CHAPTER 1

HISTORIC OVERVIEW

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CHAPTER 1 – HISTORIC OVERVIEW

For nearly 50 years (1943-1990), the history of the Manhattan Project and the Hanford Site's role in it and the subsequent Cold War have been largely invisible. For national security reasons, the government labeled these facilities "classified" and deliberately kept the public in the dark about what was going on behind the fences. With the end of the Cold War, this history no longer needs to be kept secret. In recognition of the global significance of events that occurred on an isolated stretch of the Columbia River in south-central Washington State, the Richland Operations Office of the U.S. Department of Energy (DOE) conducted a 4-year project to document the plutonium production facilities at the Hanford Site (Figure 1.1). Through this project, the roles these facilities played in World War II and the Cold War Era, together with the perspective of the workers who staffed them, are captured in this book supplemented with historic photographs and oral histories – many of which appear in print for the first time.

PURPOSE AND OBJECTIVES

The dual purpose of this book is to formally identify the Hanford Site Manhattan Project and Cold War Era Historic District and to preserve in words, diagrams, and photographs its significant structures because the majority of these structures have been or will be demolished. The designation of the Manhattan Project and Cold War Era facilities at the Hanford Site as a Historic District came about through an agreement between the U.S. Department of Energy and the Washington State Historic Preservation Office (SHPO).

The National Historic Preservation Act (NHPA) was passed in 1966. Among the reasons for its passage, Congress noted that "historic properties significant to the Nation's heritage are being lost or substantially altered, often inadvertently, with increasing frequency" (16 USC 470(b)(3)). From its inception, NHPA has emphasized the identification and protection of discrete sites, buildings, structures, and objects tied to a specific geographic location.

The principal tool for identification, evaluation, and protection of significant properties is the National Register of Historic Places – the "nation's inventory of historic places and the national repository of documentation on the variety of historic property types, significance, abundance, condition, ownership, needs, and other information" (NPS 1990, p. 1). Section 106 of NHPA prescribes for each undertaking that Federal agencies "take into account the effect of the undertaking on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register" (16 USC 470f).

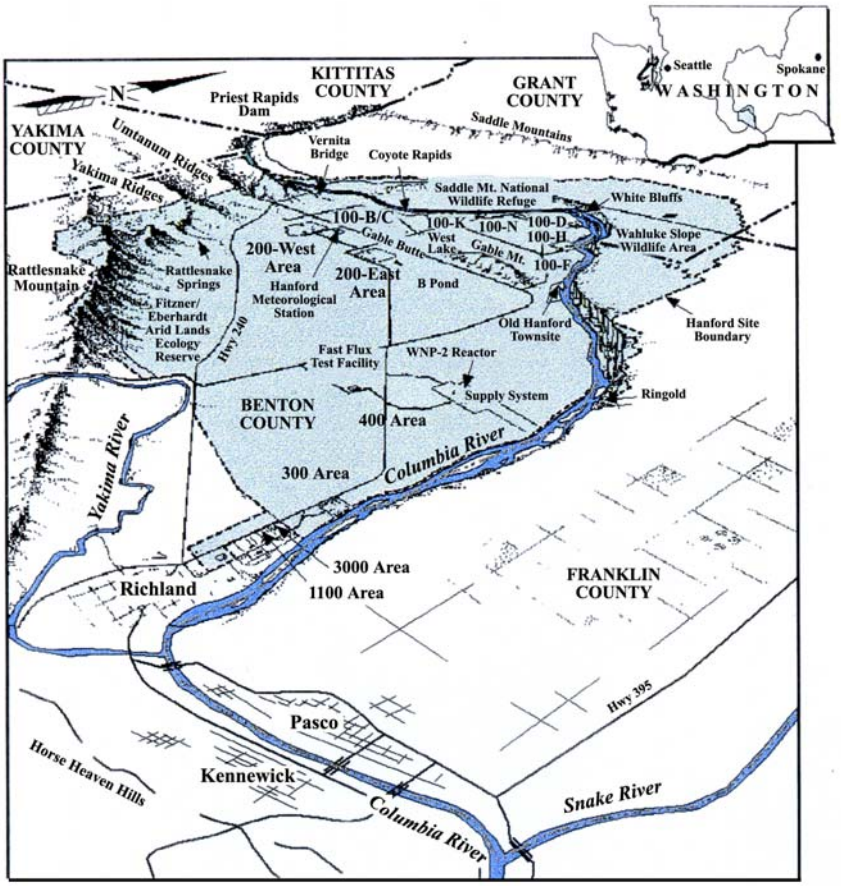


Figure 1.1. *Hanford Site (Gray Area) Located in Washington State along the Columbia River*

Section 110 of NHPA requires that agencies "initiate measures to assure [sic] that where…an historic property is to be substantially altered or demolished, timely steps are taken to make or have made appropriate records…for future use and reference" (16 USC 470h-2(b)). With the change in mission from plutonium production to environmental restoration and the demolition of surplus properties, DOE resolved to satisfy its responsibilities under NHPA by initiating an innovative management strategy for those properties related to the Manhattan Project and Cold War.

In 1996, DOE, SHPO, and the Advisory Council on Historic Preservation signed a Programmatic Agreement that modified compliance with Sections 106 and 110 of NHPA with respect to historic buildings on the Hanford Site (DOE 1996a). In deliberations leading to the Programmatic Agreement, DOE and SHPO first determined that the Hanford Site was a designed industrial landscape whose buildings, grouped by function within designated geographic complexes, were united historically and thematically by the production of plutonium for national defense. Given this finding, DOE and SHPO agreed that the Hanford Site met the requirements for an Historic District, as defined by the National Park Service, because it possessed a "significant concentration, linkage, or continuity of sites, buildings, structures, or objects united historically…by plan or physical development" (NPS 1990, p. 5). By identifying the Hanford Site Manhattan Project and Cold War Era Historic District in the Programmatic Agreement, DOE and SHPO were able to replace the documenting and mitigating of each building at the Hanford Site with a systematic treatment of the Hanford Site itself.

Key to this strategy was to develop property types and identify the buildings that best represented each type. DOE selected the primary functions of Fuel Manufacturing, Reactor Operations, Chemical Separations, and Plutonium Finishing as well as the support functions of Waste Management, Research and Development, Site Security, Military Operations, Health and Safety, and Infrastructure as categories in which the buildings would be classified. Using this classification matrix, DOE assigned 1100 buildings to specific property types and evaluated each building for its eligibility for listing in the National Register of Historic Places as a contributing or non-contributing property within the Historic District. Of the 527 buildings determined to be contributing properties, DOE and SHPO ultimately selected 190 (initially 187) properties for individual documentation using Historic American Engineering Records (HAER), expanded Historic Property Inventory Forms (ExHPIF), or standard Historic Property Inventory Forms (HPIF). These key properties collectively represented the events and activities that took place on the Hanford Site from 1943-1990. The *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan* (Marceau 1998) shows the original classification matrix of 1100 buildings and the properties recommended for individual documentation.

DOE's current mission of environmental restoration, which includes the demolition of surplus properties, will adversely affect the historic properties that comprise the Hanford Site Manhattan Project and Cold War Era Historic District. However, SHPO agreed that recording the key events that occurred at the Hanford Site from 1943-1990 in this book and documenting each of the 190 representative properties would address the effects of decommissioning and environmental restoration. This book, *History of the Plutonium Production Facilities of the Hanford Site Historic District, 1943-1990*, satisfies Stipulation VI of the Programmatic Agreement (DOE 1996a) under which DOE agreed to write a "synthetic, integrated Hanford Site historic narrative" that would include:

- Contextual information about the different property types and processes associated with them – see Chapter 2 of this book and Appendix B on the Internet
- Numbers and locations of buildings within property types – see Table A.5 in the *Hanford Site Manhattan Project and Cold War Historic District Treatment Plan* at http://www.hanford.gov/doe/culres/historic/index.htm (Marceau 1998) and Appendix B on the Internet
- Descriptions of changes in technology, design, and use of property types over time – see Appendix B on the Internet
- Photographs, plans, and cross sections of representative examples of the different property types – see Appendix B on the Internet

The narrative was further defined in the *Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan* (Marceau 1998), which was written in compliance with Stipulation IV of the Programmatic Agreement. In scope,

the historic narrative would be a "report which will chronicle the history of the Hanford Site, its technology, and the people who worked here" (DOE 1998a, p. 1). Selection of the word "chronicle" was deliberate since, according to *Webster's New Collegiate Dictionary*, it defined the end state of the report as an "historical account of events arranged in order of time *without analysis or interpretation*" (emphasis added). From the outset, this book was designed to reflect the emphasis of the National Register program and the Secretary of the Interior's Standards and Guidelines for Historical Documentation.

> ***"[Historical] Documentation is a detailed record, in the form of a report or other written document, of the historic context(s) and significance of a property. Historical research to create documentation uses archival materials, oral history techniques, ethnohistories, prior research contained in secondary sources and other sources to make a detailed record of previously identified values or to investigate particular questions about the established significance of a property or properties… Documentation generally results in both greater factual knowledge about the specific property and its values, and in better understanding of the property in its historical context…Documentation should incorporate rather than duplicate the findings of previous research."* - 48 FR 44716, p. 44729

In keeping with this guidance (see sidebar box), the authors of this book used existing information to the fullest extent possible to recount the events that occurred at the Hanford Site from 1943 through 1990 to highlight the significance of the buildings and structures in which those events occurred. The purpose of this book is not an academically oriented history of the Hanford Site. The authors of this book did not use a uniform or classic historic approach, nor did they interpret or explain the events that took place at the Hanford Site over the past 50 years. Rather, they sought to present these events like a reporter who informs the audience and allows for independent conclusions.

The authors of this book were selected because of their backgrounds in the particular topics to be researched. The authors' biographies are in Appendix A on the Internet (http://www.hanford.gov/docs/rl-97-1047/biographies/index.htm). The variety of topics covered required authors from various disciplines with the result that each author took a slightly different approach to the method of research and manner of recording it. The sections in Chapter 2, therefore, are not always parallel in the type or depth of focus. While the reader may question the extent of the research underlying each section, how critically the authors examined their sources, the explicit or implicit filters they applied in selecting pertinent passages, and how completely they synthesized their data, the authors neither present, nor intend that this book be taken as, a definitive history of the Hanford Site or an investigation or interpretation of specific issues, such as the long-term effects of operations on groundwater. That undertaking we leave to others, who we hope will use the resources in this book as a springboard for their work.

This book provides a brief chronicle of the facilities at the Hanford Site organized by the processes that define their reason for existence, mainly Fuel Manufacturing, Reactor Operations, Chemical Separations, Plutonium Finishing, and related activities. It complies with the requirements of the National Historic Preservation Act to document the facets of the properties that qualify them for listing in the National Register and their role in the Manhattan Project and subsequent Cold War. It also corresponds with the intent of the National Register program to recognize physical properties and document their appearance and importance.

SCOPE

This book covers the time period 1943-1990 – the years spanning the Manhattan Project and the Cold War. Chapter 1 is a historic overview summarizing some of the events that accounted for and influenced the creation and operation of the Hanford Site as well as some of the activities undertaken on the Hanford Site in response to these events.

Chapter 2 consists of twelve sections with details, descriptions, and illustrations of the primary production operations (manufacturing the fuel, irradiating it in the reactors, chemically separating it to isolate plutonium, and finishing the plutonium into the form needed for a bomb), support activities (construction, waste management, research and

development, security, military operations, worker health and safety, and infrastructure), and most importantly a perspective from the workers who made it all happen.

Chapter 3 is a guide to resources and information for future researchers. Ideas generated or omissions noted within this text may be investigated more fully by the interested reader using these resources.

Chapter 4 looks to the future and provides recommendations for future uses for some of the facilities still standing on the Hanford Site. It envisions opportunities for economic development and heritage tourism as a way to extend vestiges of the past into the 21st century.

Appendix A contains the biographies of those who contributed directly or indirectly to the book. Appendix B contains the Historic American Engineering Records and Historic Property Inventory Forms for the focal properties designated in the Programmatic Agreement for individual documentation.

The following topics are not discussed because they are either treated more extensively or appropriately in other documents or they fall outside the scope of this book:

Waste Products/Cleanup: Each step in the plutonium production cycle had an associated waste stream. This book discusses only that wastes were produced during the fuel manufacturing, irradiation, separation, and concentration processes and were introduced into the environment in pits, drains, cribs, trenches, basins, and tanks. With the exception of personal and environmental health, no other topic in this book will likely generate as much concern among readers – particularly those within proximity of the Hanford Site. However, this book will not explore or debate the consequences or effects of the waste products generated and stored on the Hanford Site nor the cleanup of the Hanford Site which began after the Cold War Era.

Health Effects: This book discusses the programs established to monitor worker health and safety and the environment. The long-term effectiveness of these programs and the effects of working with or living near radiation and chemicals are briefly discussed. These topics are covered more appropriately and explicitly in other sources including the results reported from the Hanford Environmental Dose Reconstruction (HEDR) Project (HEDR 1994a), the Screening Assessment and Requirements for a Comprehensive Assessment, Columbia River Comprehensive Impact Assessment (DOE 1998a), as well as risk assessments contained in Environmental Impact Statements, CERCLA documents, and Safety Assessment Reports.

The Decision to Use the Bomb: The decision to use atomic weapons was not made lightly. The question was debated vigorously on moral, political, technical, and military grounds. President Truman's reasoning, the views of individual members of the Interim Committee, and the split within the Scientific Panel culminating in a petition Leo Szilard drafted and 155 of the scientists developing the bomb signed arguing that it not be used are all well documented. Readers interested in this topic are directed to sources such as The Making of the Atomic Bomb (Rhodes 1986) or "Hiroshima: World Culture as the Event War" (Lanouette 1999).

The agreement with SHPO and the Advisory Council on Historic Preservation requires publishing this book as a hard copy, which limits the amount of space we can devote to each topic. Each of the chapters and sections in Chapter 2 has been restricted to roughly fifty pages including figures. Because of cost constraints inherent in publication, the appendices have been published only on the Internet at http://www.hanford.gov/docs/rl-97-1047/index.htm. If funding permits, a compact disk containing the complete book may be available in the future.

This book gives the historical measurements, which are usually rounded off. For exact measurements, the reader should refer to the original documents.

The References Cited Section lists the resources used in researching this book. The Bibliography lists additional resources not used directly but which may be of interest to the reader in pursuing additional research.

SETTING THE STAGE

The Hanford Site was established for one reason – to produce plutonium for use in weapons. With a production record of 54.5 metric tons (quantity published to date, which is 60 percent of the total amount of weapons-grade plutonium produced by the United States), the Hanford Site fulfilled its Manhattan Project and Cold War mission (DOE 1996b, Figures 6 and 7, Table 2). At its inception, the Hanford Site was largely an experiment, the production-scale culmination of two key events – the demonstration of a controlled, sustainable nuclear chain reaction capable of transforming uranium into plutonium, and the discovery of a process to separate plutonium from uranium following irradiation.

The theme that the Hanford Site was an experiment runs throughout the Manhattan Project and the Cold War Era. Creating plutonium was a new science. Producing plutonium on an industrial scale was a major challenge. The time pressures of war added to the uncertainties that accompanied each decision. Yet critical decisions had to be made within very short time frames despite the uncertainties. Such a situation helps explain the mistakes, the risk taken, the resourcefulness of the workers, and the achievements that made the Hanford Site a Historic District today.

Throughout the book we read of decisions that had to be made without full knowledge of the consequences and the workers who met these challenges. In describing the need to proceed with the Manhattan Project and construct the Hanford Site, Lieutenant General Leslie R. Groves as commander of the Manhattan Project relates "We would go ahead with their design and construction as fast as possible, even though we would have to base our work on the most meager laboratory data...we could not afford to wait" (Groves 1983, p. 72). We read of how one of the production line crew solved the problem of aluminum crumpling within 24 hours when manufacturing the fuel elements. We also learn of the problems of isolating the plutonium once it had been created: "The lack of actual irradiated uranium for experimentation, ignorance of the chemical properties of plutonium, and engineering inexperience with high radiation levels, complicated the development effort [to extract and purify the plutonium] tremendously" (DOE 1997e, p. 171). Describing the challenge of chemically separating out plutonium, one of Du Pont's chemical engineers, Raymond Genereaux, illustrates the theme of the Hanford Site as an experiment: "We realized immediately we had to design flexibility into it if we were going to move ahead and get any designing done before we knew for sure what we were doing, before we knew what the process would be" (Genereaux, quoted in Sanger 1989, p. 40).

Creating plutonium was a challenge because it is an artificially made element. It exists only rarely in nature. Plutonium is a product of uranium fissioning and is created by the absorption of neutrons within the nuclei of uranium atoms that have been subjected to neutron bombardment (see Figure 1.2). Plutonium is not a daughter product of uranium. It does not form directly from uranium. Rather, the transmutation is a two-stage process in which an intermediary element is formed. Under neutron bombardment within a nuclear reactor, uranium-238 (one of the two main isotopes of uranium, element 92) first changes to uranium-239, a highly unstable isotope marked by the addition of an extra neutron. Within 20 minutes, on average, uranium-239 spontaneously transforms to neptunium-239 (element 93). With a half-life of only 2.3 days, neptunium is also highly unstable, and when undergoing radioactive decay, spontaneously changes to plutonium-239 (element 94), a radioactive element with a half-life of approximately 24,000 years (Rhodes 1995).

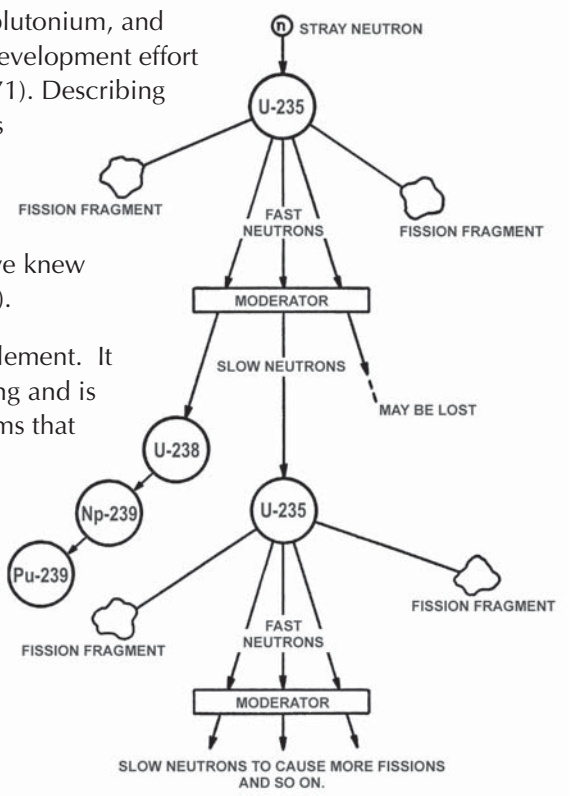


Figure 1.2. *Creation of Plutonium—a Product of Uranium Fissioning*

Plutonium is highly fissile. This means its nuclei can be readily split, releasing large amounts of energy either under controlled conditions as a nuclear fuel or under uncontrolled conditions as a nuclear explosion. Physicists have devoted years to intense research to arrive at this understanding. In fact, theoretical physicists predicted the transmutation of uranium to plutonium several years before they actually observed it. The discovery of plutonium and its chemistry was intimately tied to the investigation of the fissile properties of uranium.

NUCLEAR FISSION

> ***"The discovery of fission came just as Germany was girding itself to abandon expansion by intimidation and resort to armed conquests…World War II erupted at a moment when the promise of atomic energy had progressed from being possible to being probable. It was not clear whether this energy could be released explosively however."*** **- Sublette 1999, p.1**

The nuclear arms race began with the race to develop the atomic bomb. The United States was a late entrant whose participation came largely at the prodding of emigrant scientists including Leo Szilard, Edward Teller, and Eugene Wigner who "regarded it as their responsibility to alert Americans to the possibility that German scientists might win the race to build an atomic bomb and to warn that Hitler would be more than willing to resort to such a weapon" (Gosling 1999, p. vii). Great Britain, Japan, and the Soviet Union also participated in this race; however, "only the Americans… protected by oceans on both sides, managed to take the discovery of fission from the laboratory to the battlefield and gain a short-lived atomic monopoly" (Gosling 1999, p.vii).

The history of high-energy physics and nuclear fission is extensive. Its retelling is well beyond the scope of this book. However, a recounting of key events is instrumental in establishing a framework for the existence of the Hanford Site and the establishment of the Historic District. Many dates and events could be chosen as the starting point, but this much abbreviated discussion begins in 1932 when James Chadwick demonstrated the existence of the neutron, or non-charged particle, within the nucleus of an atom. Later that year, J. D. Cockroft and E. T. S. Walton successfully split lithium atoms in a particle accelerator (Gosling 1999, Sublette 1997). In 1933, Szilard first envisioned the dual potential of the atom when he surmised that the collision of neutrons within a chain reaction would release energy and speculated on the use of this energy in making bombs. Szilard formalized these thoughts in a patent application on July 4, 1934 that described how explosions could be induced through chain reactions and introduced the concept of critical mass. It would be 2 years, however, before the British Admiralty accepted Szilard's offer of his patents (Sublette 1997).

In contrast to prevailing studies that required a high energy source to accelerate positive-charged proton beams and alpha particles, Enrico Fermi experimentally bombarded 63 elements with neutrons, reasoning that little resistance would be encountered by uncharged particles entering the nucleus. One of the experimental elements was uranium (Gosling 1999). Over the next several years, the international scientific community focused on neutron bombardment as a more promising technology for splitting atoms and uranium as a key element.

> ***In July 1937, Japan invaded China and in November joined Germany and Italy in the Axis Alliance.***

Otto Hahn and Fritz Strassmann, working in Berlin, discovered that uranium nuclei split into radioactive barium and fragments of uranium. Hahn published the experimental results in *Naturwissenschaften* on December 21, 1938 (Sublette 1997). On January 13, 1939, Otto Frisch substantiated these results and, together with Lise Meitner, an Austrian émigré living in Sweden at the time, calculated the unprecedented amount of energy released. Although she did not receive the credit she deserved, Meitner is recognized as the first to theorize the fission process (Meitner and Frisch 1939, Simes 1996). Based on their calculations, Frisch applied the term "fission," from biological cell division, to name this process (Sublette 1997, Gosling 1999).

Niels Bohr announced the results of the Hahn-Strassmann uranium experiments and the Meitner-Frisch calculations to the American scientific community on January 26, 1939. In March of that year, a Columbia University team consisting of Fermi, Szilard, Walter H. Zinn, and Herbert Anderson discovered that "at least two secondary neutrons emerge from each neutron-induced fission" of uranium (Rhodes 1986, p. 294). On August 31, Bohr and John A. Wheeler, working at Princeton University, published their theory that the isotope uranium-235, present in trace quantities within uranium-238, was more fissile than uranium-238 and should become the focus of uranium research. In this publication, they also postulated that a then unnamed, unobserved transuranic element (referred to simply as 94^{239} or, more descriptively, as "high octane") produced during fissioning of uranium-238 would be highly fissionable (Sublette 1997). With these findings, the theoretical foundation for atomic energy was substantially set.

On September 1, 1939, Germany initiated World War II by invading Poland.

In response to this aggressive act by Germany, U.S. uranium research objectives began to alter on October 11, 1939 when Alexander Sachs delivered a letter to President Franklin D. Roosevelt drafted by Szilard and signed by Albert Einstein. Szilard was among the most vocal of those advocating a program to develop bombs based on recent findings in nuclear physics and chemistry. The letter warned the President of the potential for and consequences of atomic weapons and prevailed upon him to take immediate action to counter the work being done in Germany at the Kaiser Wilhelm Institute in Berlin. Ten days later the Presidential Advisory Committee on Uranium met for the first time in Washington D.C. President Roosevelt had acted quickly, but the Committee, under the direction of Lyman Briggs, initially would take a cautious approach by continuing to focus primarily on uranium research and not applications (Sublette 1997).

On April 9, 1940, Germany invaded Denmark and Norway and on May 10 invaded Holland, Belgium, and France.

If German scientists were moving ahead as quickly in developing an atomic bomb as the German army was in subjugating Western Europe, the United States needed to accelerate its uranium program. The National Defense Research Committee replaced the Presidential Advisory Committee on Uranium in June 1940 and afforded the American scientific community a presence within the executive branch. Vannevar Bush, president of the Carnegie Foundation, was appointed head of the new committee. By eliminating the former committee's military members, Bush concentrated power with the scientists. He also introduced security and secrecy into nuclear research by "barr[ing] foreign-born scientists from committee membership and block[ing] the further publication of articles on uranium research" (Gosling 1999, p. 7). These themes of secrecy and exclusion would become hallmarks of the nuclear weapons program. Using $40,000 awarded by the National Defense Research Committee, in November 1940 Fermi and Szilard began constructing a sub-critical, graphite-moderated, uranium oxide "pile" (the original name for reactors) at Columbia University to further investigate chain reactions (Sublette 1997).

On June 28, 1941, the nuclear scientific community assumed an even stronger presence within the government when President Roosevelt established the Office of Scientific Research and Development by executive order. Vannevar Bush was named its director and now reported directly to the President. President Roosevelt created the Office of Scientific Research and Development within a week of Germany invading the Soviet Union and less than a month following a presentation Tokutaro Haiwara made at the University of Kyoto in which he speculated about the potential for a fusion explosion using a fission ignition – the basis for thermonuclear weapons (Sublette 1997, Gosling 1999).

The British counterpart to the Office of Scientific Research and Development, the MAUD Committee, issued its final report on July 15, 1941, in which they described the technical details of atomic bombs together with proposals and cost estimates for their development (Sublette 1997). "Americans had been in touch with the MAUD Committee since fall

1940, but it was the July 1941 MAUD report that helped the American bomb effort turn the corner. Here were specific plans for producing a bomb, produced by a distinguished group of scientists with high credibility in the United States." (Gosling 1999, p. 9).

Meeting with President Roosevelt and Vice President Henry A. Wallace on October 9, Bush relayed the findings in the MAUD report and received instructions from the President to quicken the pace of research to determine the feasibility of a bomb but not to proceed to production without explicit authorization (Gosling 1999). On November 6, the National Academy of Sciences, under Arthur Compton, issued a report that verified the conclusions of the MAUD report, although less optimistically. Compton estimated that "a critical mass of between two and 100 kilograms of uranium-235 would produce a powerful fission bomb and that for $50-100 million isotope separation in sufficient quantities could be accomplished" (Gosling 1999, p. 10). Bush delivered the report to President Roosevelt on November 27. Building on this report and acting on the President's instructions, Bush organized an accelerated research project on December 6 that would investigate gaseous diffusion, electromagnetic separation, centrifuge separation, chain reactions, heavy water production, and plutonium production. At the same time, he began laying the foundation for engineering studies and the construction of pilot plants (Gosling 1999, Sublette 1997).

On December 7, 1941, Japan attacked Pearl Harbor.

America's entry into the war ended the bureaucratic struggling that had characterized fission study by focusing investigations on the production of atomic weapons (Sublette 1999). The National Defense Research Committee yielded all "broad policy decisions relating to uranium" to the Top Policy Group consisting of Vice President Wallace, Secretary of War Henry L. Stimson, Army Chief of Staff George C. Marshall, Vannevar Bush, and James Conant (Gosling 1999, p. 10). America's full commitment to the development of fission weapons came on December 18, 1941, when Arthur Compton called the first meeting of the newly created S-1 Committee (Section One, Uranium, of the Office of Scientific Research and Development). The Committee awarded $400,000 to Ernest O. Lawrence to continue his work on electromagnetic separation of uranium-235 at the University of California, Berkley (Gosling 1999). "With the United States now at war and with the fear that the American bomb effort was behind Nazi Germany's, a sense of urgency permeated the federal government's science enterprise…By spring 1942…the situation had changed from one of too little money and no deadlines to one of a clear goal, plenty of money, but too little time" (Gosling 1999, p. 10).

The accelerated research program Bush established at the end of 1941 and President Roosevelt approved on January 19, 1942 meant several lines of research were being investigated concurrently so an atomic bomb could be delivered to the President by 1944. For the development of the Hanford Site, the most pertinent research was that devoted to plutonium production through a sustained chain reaction using uranium as a fuel. In January 1942, Compton moved "pile research" (reactor research) from Columbia University to the University of Chicago where he established the Metallurgical Laboratory. Over the next several months, Fermi's experiments there brought theory ever closer to reality. In April, his efforts shifted from "demonstrating feasibility to securing graphite and uranium of adequate purity and in sufficient quantity to build the [Chicago Pile 1 or CP-1] reactor" (Sublette 1997). By mid-August, Fermi had evinced that a chain reaction was a certainty. On December 2, 1942, at 3:49 p.m., Fermi and Samuel K. Allison achieved the world's first controlled, self-sustained nuclear chain reaction in an experimental reactor of natural uranium and graphite constructed under the squash courts at Stagg Field (Gosling 1999, Sublette 1997). The stage had been set for reactor operations at the Hanford Site.

ISOTOPE SEPARATION

Concurrent with the search for technologies to produce the isotopes uranium-235 and plutonium-239 was the search for a method to separate these isotopes once they were produced. Vastly different techniques would be required.

Early in 1939, Niels Bohr surmised that uranium-235 and uranium-238 possessed differing fission characteristics and concluded that the observed slow fission in uranium was attributable to uranium-235. Together with John A. Wheeler, Bohr published this theory on August 31. By March 1940, John R. Dunning of Columbia University experimentally

confirmed their finding in collaboration with Alfred O. Nier of the University of Minnesota (Gosling 1999). However, to determine whether uranium-235 would support an explosive nuclear chain reaction, concentrated samples of this isotope, sufficient in size to form a critical mass, would need to be obtained. Separation of this isotope from uranium could not be accomplished through chemical means because isotopes of the same element, such as uranium-235 and uranium-238, are chemically indistinguishable. Physical separation, based solely on their differing atomic weights, would have to be used. Electromagnetic separation, centrifuge separation, and gaseous diffusion were candidate techniques.

Each of these techniques had champions, and each had problems to overcome in moving from an experimental to a production stage. Entirely new technologies would have to be designed and built with many of their components individually manufactured to exacting tolerances not found in standard industrial applications. Therefore, on May 23, 1942, given the uncertainties of success for any one of these separation methods to concentrate uranuim-235, or at this point the likelihood of sustaining a nuclear reaction that would transform uranium into plutonium, Conant urged the S-1 Committee to proceed with all options simultaneously "regardless of cost." He argued convincingly that "redundant development" would reduce the time required to produce enriched uranium or plutonium (Sublette 1997). The decision to push all options forward as fast as possible "reflected the inability of the committee to distinguish a front-runner and its consequent unwillingness to abandon any method. With funds readily available and the outcome of the war conceivably in the balance, the S-1 leadership recommended that [gaseous diffusion, centrifuge and electromagnetic separation, and plutonium production] proceed to the pilot plant stage and to full production planning" (Gosling 1999, p. 11).

To ensure timely success, the United States "simultaneously pursued plutonium and highly enriched uranium as fissile materials for atomic weapons" (DOE 1997e, p. 136). Implementation of this strategy with respect to uranium enrichment led to the establishment of the Clinton Engineer Works, renamed the Oak Ridge Reservation after the war. Research that resulted first in the discovery of plutonium and then to a chemical means by which it could be separated from uranium led to the establishment of the Hanford Engineer Works, later renamed the Hanford Site.

In their August 1939 publication, Bohr and Wheeler had theorized that a uranium fission byproduct – assigned the nondescript elemental placeholder 94^{239} – would be highly fissionable. Following this lead, Edwin McMillian and Philip Abelson announced on May 27, 1940 that they had discovered a new element – element 93^{239} (neptunium) – produced by neutron bombardment of uranium-238 within the cyclotron at the University of California, Berkeley. Demonstration of this short-lived transuranic element was significant because neptunium, if the Bohr-Wheeler theory of transmutation were correct, would become 94^{239} following an additional beta-decay. Glenn T. Seaborg and Arthur Wahl, also of the University of California, Berkeley, brought closure to the theory when they successfully demonstrated the existence of element 94^{239} on February 26, 1941 (Sublette 1997). In 1942, they named this element plutonium, after the protocol of naming new elements after the outer planets, that is, uranium (Uranus), neptunium (Neptune), and plutonium (Pluto) (Rhodes 1986).

Having demonstrated that plutonium-239 could be created as a fission product from uranium-238, Seaborg, together with Emillio Segrè, began to investigate the chemical properties of plutonium. On May 18, 1941, fewer than 3 months after its discovery, they concluded that plutonium-239 was 1.7 times as fissionable as uranium-235, thereby "proving it to be an even better prospective nuclear explosive" (Sublette 1997). Seaborg subsequently moved to the Metallurgical Laboratory in Chicago at Compton's request where he began work on developing a "large-scale, remote-controlled" chemical separation and purification process to extract and concentrate plutonium (Rhodes 1986, p. 381). On August 20, 1942, Seaborg successfully concluded a sequence of chemical oxidation and reduction cycles using "ultramicrochemical equipment" that produced a microgram (a millionth of a gram) of plutonium (Rhodes 1986, p. 414). While Sublette (1997) correctly notes that Seaborg had identified a methodology that could be used on an industrial scale, actual scale-up of the equipment "had to keep abreast of, and in some cases ahead of, the development of the [separations] process itself" (Groves 1983, p. 85).

MANHATTAN PROJECT: CREATION OF THE HANFORD SITE

> ***"…with the agreement of everyone who held any degree of responsibility for the project, I had decided almost at the very beginning that we would have to abandon completely all normal, orderly procedures in the development of the production plants. We would go ahead with their design and construction as fast as possible, even though we would have to base our work on the most meager laboratory data. Nothing like this had ever been attempted before, but with time as the controlling factor, we could not afford to wait to be sure of anything."*** **- Groves 1983, p. 72**

Fermi had demonstrated that a controlled, self-sustained nuclear reaction capable of producing plutonium-239 was no longer theoretical. Seaborg had provided a means whereby plutonium could be chemically separated from irradiated uranium. The prerequisites necessary to enable operations at the Hanford Site had been met. Nevertheless, the gap between laboratory demonstrations and full-scale production was formidable. Lieutenant General Leslie R. Groves, who would command the Manhattan Project, both encouraged and demanded risk taking in bridging that gap.

BEGINNINGS OF THE MANHATTAN PROJECT

By mid-1942, government-supported research was concentrated at Columbia University in New York, the University of California in Berkeley, and the University of Chicago Metallurgical Laboratory (DOE 1997e). Although directed towards the development of atomic weapons, the S-1 program was still largely an academic endeavor in which scientists held the leadership role. This changed within a matter of months.

> ***"The need for security suggested placing the S-1 program within one of the armed forces, and the construction expertise of the Corps of Engineers made it a logical choice to build the production facilities…With this reorganization in place, the nature of the American atomic bomb effort changed from one dominated by research scientists to one in which scientists played a supporting role in the construction enterprise run by the United States Army Corps of Engineers."*** **- Gosling 1999, pp. 11-12**

As early as October 9, 1941, the military presence, which had largely been excluded with the establishment of the National Defense Research Committee in June 1940, began to reemerge when President Roosevelt authorized Bush to "explore construction needs with the Army" (Gosling 1999, p. 9). The S-1 Committee decision on May 23, 1942 to move from laboratory research to full production prompted a central role for the military since the prevailing thought was that weapons production should be "brought under an organization experienced in producing weapons" (Sublette 1999, p. 2). Bush selected the U.S. Army Corps of Engineers.

In June 1942, President Roosevelt approved $85 million to support atomic weapons development, which was a phenomenal increase from the $6,000 supplied for "uranium research" just 2 years earlier (Sublette 1997). The Corps assumed responsibility for process development, procurement, design, and site selection. They received $54 million in funding. The remaining $31 million was reserved for research and pilot plant studies under the direction of the S-1 Committee in the Office of Scientific Research and Development (Gosling 1999). However, this split between the Corps and Office of Scientific Research and Development proved counterproductive, and on June 18, 1942, Brigadier General Wilhelm D. Styer ordered Colonel James C. Marshall to organize an Army Corps of Engineer District devoted exclusively to managing and coordinating atomic weapons development. Initially named the Laboratory for the Development of Substitute Metals, by August 13, 1942, the organization was renamed the Manhattan Engineer District.

Such an industrial scale project under wartime conditions and pressure to produce demanded effective, proven leadership. Just a month after its formation, the Army tapped Lieutenant General (then Colonel) Leslie R. Groves to head the Manhattan Engineer District and its namesake, the "Manhattan Project." Groves was appointed on September 17, 1942 and "seized immediate and decisive control. In just two days he resolved issues that had dragged on for months under Compton" (Sublette 1999):

- Purchasing and shipping 1,250 tons of high quality Belgian Congo uranium to Staten Island
- Purchasing 52,000 acres on the Clinch River in Tennessee
- Raising emergency procurement priority to AAA, the highest allowed by the War Production Board (Gosling 1999, Sublette 1997).

Groves' decisiveness was rewarded on September 23, 1942 with his promotion to Brigadier General. He firmly believed that the exigencies of war required that the focus shift from laboratory research to full-scale development and production in the shortest time possible. He impressed this view on the scientific community. "Groves' pushy, even overbearing, demeanor won him few friends among the scientists on the Manhattan Project (in particular a special enmity developed between Groves and Szilard). Many detested him at the time, considering him a boor and a buffoon. It was only after the war that many scientists began to appreciate how critical his organizational and managerial genius was to the MED" (Sublette 1999, p. 3).

On October 15, 1942, Groves asked J. Robert Oppenheimer to head a laboratory in which research on the physics and design of atomic weapons would be centralized. The S-1 Executive Committee had discussed the need for this laboratory on September 13. On November 16, 1942, Groves and Oppenheimer selected a site on the Los Alamos mesa in New Mexico for the laboratory. The location was code-named "Site Y." In December 1942, Groves initiated development planning for the Clinton Engineer Works, code-named "Site X." This location on the Clinch River in Tennessee was to contain an experimental reactor, a chemical separations plant, and an electromagnetic separation facility (Sublette 1999).

Construction of the Clinton Engineer Works was predicated on the need to accelerate an already compressed schedule. Meeting with the Military Policy Committee on November 12, 1942, Groves and Conant argued that centrifuge separation should be abandoned and that gaseous diffusion, electromagnetic separation, and plutonium production should bypass the pilot plant stage and proceed directly to full-scale operations. The S-1 Executive Committee seconded these decisions on November 14 (Gosling 1999). On December 28, 1942, following a final review of the decisions reached by the Military Policy Committee and S-1 Executive Committee, President Roosevelt approved $500 million for the Manhattan Project (Gosling 1999, Sublette 1997). "No schedule could guarantee that the United States would overtake Germany in the race for the bomb, but by the beginning of 1943 the Manhattan Project had the complete support of President Roosevelt and the military leadership, the services of some of the nation's most distinguished scientists, and a sense of urgency driven by fear" (Gosling 1999, p. 17).

SELECTION OF THE HANFORD SITE

Even before Fermi had achieved a sustained nuclear reaction, competition had begun to design a prototype large-scale production reactor. In June 1942, Thomas V. Moore and his team developed a plan for a helium-cooled pilot reactor to be built at the Argonne Forest Preserve outside Chicago. Because of the spherical segmentation of its outer shell, the design came to be known as the "Mae West." Eugene Wigner and Gale Young proposed a vertical water-cooled design, while Leo Szilard championed a reactor cooled by bismuth, a liquid metal. On October 5, with design frozen for months by indecision, Groves gave Compton and the Metallurgical Laboratory scientists 1 week to reach a decision with the admonishment that "even wrong decisions are better than no decisions" (Gosling 1999, p. 27). Compton decided to build a water-cooled reactor at Argonne, and an air-cooled semiworks at the Clinton Engineer Works. The shift from helium to air reflected an analysis by E. I. Du Pont de Nemours and Company in Wilmington, Delaware of the options proposed by the Metallurgical Laboratory (Gosling 1999). Du Pont soon assumed an influential role in the design, engineering, and construction of plutonium production and separation facilities.

The Manhattan Project was on a very fast track. One example among many serves to illustrate this point. In December 1942, the M. M. Sundt Company began constructing the Los Alamos Laboratory "without plans or blueprints in order to finish as quickly as possible" (Sublette 1997, p. 10). Speed, while paramount, did not completely displace the concern for safety, however. The Manhattan Project was investing in unproven technology, much of it being developed

for the first time. Safety consideration as much as the requirement of secrecy ultimately led Groves to locate facilities in isolated areas.

For example, Compton's decision to relocate Fermi's second experimental reactor (CP-2) from the University of Chicago to the Argonne Forest Preserve was based primarily on safety considerations, that is, the potential effect on an urban population should something go wrong with the reactor. This was also the concern underlying Groves' decision to relocate the X-10 pilot plutonium reactor and separation plant from Chicago to Tennessee. This latter decision, however, had an unanticipated consequence. A pilot facility at the Clinton Engineer Works negated the construction of a full-scale production complex there due to siting requirements. There was not enough room for both facilities, and Knoxville was too close (Gosling 1999). Additionally, Groves was concerned that if an accident did occur in an untested, large reactor, the uranium enrichment facilities planned for the Clinton Engineer Works could be destroyed as well. This, together with the loss of life, would compromise the security and viability of the project (Groves 1983). Another location would have to be found for the industrial-scale plutonium production and chemical separations facilities.

On December 14, 1942, Metallurgical Laboratory scientists, Du Pont engineers, and Corps staff established the siting criteria. While he did not attend the meeting, Groves recalls his instructions to the participants and the outcome of the meeting:

> "*I arranged for a meeting at the Du Pont offices in Wilmington to ensure that the Du Pont organization, the scientific people at Chicago, and the MED would all have the same understanding of the then-accepted atomic theories, the known scientific and technical facts, the scientific probabilities, and the construction and operating problems. After reaching a common understanding, they were to arrive at the criteria for the plutonium plant site, with special attention to the limitations imposed by safety.*" - Groves 1983, p. 70

Once they agreed on the criteria, Colonel Franklin T. Matthias, one of Groves' top assistants, and Du Pont engineers Gilbert Church and A. E. S. Hall began the scouting work on December 16. Concentrating on six locations in California, Oregon, and Washington, they selected an area around the small farming and ranching communities of White Bluffs, Hanford, and Richland on an isolated stretch of the Columbia River in Washington as the closest match to the siting criteria. Groves viewed the proposed site on January 16, 1943 and authorized the establishment of what they called the "Hanford Engineer Works" (today the Hanford Site) on 670 square miles of land. The location was assigned the code name "Site W" (Gosling 1999). It was the last site selected for the Manhattan Project.

COMMUNITY SACRIFICE

The Columbia River was the focal point of the Hanford Site. Clear, cold water from this source would dissipate the heat generated from nuclear fission within the reactors. Turbines driven by the river's current at Bonneville and Grand Coulee dams would supply electrical power. And, in the eyes of Matthias and Groves at least, the area the river flowed through was sparsely settled, essentially an empty region particularly well suited for a secret government project. To those directly affected by its placement within their communities, it held a different meaning. The land on which the Hanford Site would be built was home to Native Americans with long ancestral ties to the land, and Euro-Americans who had settled in the area beginning in the 1860s. In constructing the Hanford Site, the Army forcefully removed over 1500 people who sacrificed their lands, homes, and communities to a war effort the government cloaked from their view.

Native Americans

Concentrated on the Columbia River, near inland water sources and areas of high topographic relief, the archaeological record of Native American occupation of the Hanford Site stretches back thousands of years. Typical archaeological sites include pit house villages, open campsites, fishing sites, hunting/kill sites, game drive complexes, quarries, and spirit quest sites. Physical features such as rock cairns, rock alignments, or artifacts mark these sites. Other sites relating to subsistence and ceremonial activities, which are not marked by physical remains, are also present but generally unrecognized by non-Native Americans. In 1943, the Wanapum were still resident in the Priest Rapids Valley – the area soon to become the Hanford Site. They called the Columbia River *Ci Wana* (big river) and from it took their name (the

river people). They used many of the same locations as their ancestors and engaged in a largely traditional lifestyle of fishing, hunting, and gathering, although white settlement had restricted their access to some areas. Their tie to the land was deeply rooted, but the Manhattan Project needed a secure area.

> ***"Never in their history had the Wanapums failed the government that first subdued and then ignored them. Puck Hyah Toot met with the colonel [Matthias] and heard his story that the government needed the land and that the people could roam at will no longer. He understood but fragments of the colonel's talk, realizing only that it meant another move and that all but the last old village site was lost…The last Wanapums, their hearts wavering, quietly surrendered their ancestral fishing ground and rifted canyon walls at White Bluffs, because the government said the land was needed."*** **- Relander 1956, p. 257**

When the Wanapum had to abandon their camps at White Bluffs and other locations on the Hanford Site, they concentrated their activities at Priest Rapids. They continually sought to retain entry to the Hanford Site to fish for salmon at their traditional camps since salmon was a primary staple and central to their religion. Shortly after construction began and the security fences had been established, Matthias made inquiries about "restricting the Indian fishing rights in the project area." He was told that "it would be difficult to obtain an out and out restriction, but that it might be possible to deal locally" (Matthias 1945). On September 15, 1943, Matthias entered the following in his diary:

> *"…when the Indians arrive in this area in the fall, they spend two or three weeks, usually in October, fishing in the river opposite and north of White Bluffs. These fish are cut up and dried and provide the principal item of food for the tribe during the winter. A number of proposals were offered to the Indians in which they indicated very little interest, among them was (1) a cash settlement equivalent to the value of the fish, (2) a proposal that we deliver to them the amount of fish they would normally catch in a year, (3) that they would be permitted to fish in the White Bluffs area this fall, but that they would not come back next fall, including a provision for a payment of their fishing privileges. It was finally agreed that we provide the Indians with a truck and a driver who will, at their request, during the fishing season haul the Indians and the fish from White Bluffs to their camp at Priest Rapids once a day. This would permit the Indians to do their fishing under supervision, it would avoid the necessity of their living and sleeping in the area, and would assure them of as much fish as they now get. A cash settlement to be paid annually for their privilege to fish and be in that part of the river was rejected by the Chief. His only interest was that he get fish."* - Matthias 1945, pp. 176-177

This arrangement was superseded by an arrangement made on April 2, 1944 whereby "it was agreed that these Indians would be passed through the reservation on presentation of a pass by one of three people, the Chief and his two assistants, who would be permitted to escort other Indians of the Tribe. Indians without these three people will not be admitted" (Matthias 1945, p. 57). Issuance of these passes was eventually revoked for "security reasons" (Relander 1956).

When the Wanapum were relocated for the Manhattan Project, their possessions were left behind. Frances Riddell described the consequences of relocation at one site adjacent to the Columbia River:

> *"This village was suddenly abandoned at the beginning of World War II when the Federal government took over the area in order to establish a military reservation. As the Indians were not present at the time, one informant told me, all of their houses and belongings remained just as the inhabitants had left them, the Indians were not allowed to return for their belongings. However, the houses were soon broken into by irresponsible whites and the belongings of the Indians taken or strewn about the area."* - Riddell 1948, p. 1

Concern about their material possessions was far overshadowed by their concern for their ancestors as Matthias notes of Chief Johnny Buck's request to "treat Indian Graves which we find with reverence and dispose of the bodies in some reasonable way" (Matthias 1945, p. 57). It would be nearly 15 years before the Wanapum regained access to the Hanford Site to mark their cemeteries. In the fall of 1997, indicative of post-production changes, DOE approved a long-standing request, and Wanapum Elders began to bring Tribal members, especially children and young-adults, to see and learn about their sacred sites and traditional cultural places first-hand on an annual basis.

Euro-Americans

The transformation of the Priest Rapids Valley from an agrarian to an industrial landscape began with the Manhattan Project and continued throughout the Cold War. When Matthias came to view the site in December 1942, the area was still recovering from the effects of the Depression (Sharpe 1999). The principal towns were White Bluffs, Hanford, and Richland. Smaller communities like Vernita, Allard, Wahluke, and Ringold were primarily ferrying stations facilitating crossings of the Columbia River. Active and abandoned farmsteads lay between these centers. From his vantage point, Matthias missed more than a hundred years of history and the roots these settlers had set down in the desert sand.

The Second War Powers Act authorized the Secretary of War to "acquire lands by purchase, as needed for military or other war purposes" (Sharpe 1999, p. 1). On February 8, 1943, Henry Stimson began land acquisition proceedings under directive RE-D 2161 (Gerber et al. 1997, p. 5.6). Ultimately, 670 square miles of land were withdrawn from settlement (Figure 1.3). On March 6, residents received an official notification, known as a "declaration of taking," that informed them the Army was taking their land for a top-secret project. The government provided from 90 days to as little as 48 hours for residents to relocate, forcing many to leave most of their possessions behind (Chatters 1989, Sharpe 1999). "There was no time to harvest crops or say proper goodbyes before being separated from lifelong friends" (Anonymous 1996). Walt Grisham, a White Bluffs resident, was serving in the U.S Army Air Corps stationed in Wormingford, England when he received a letter telling him his home and farm had been condemned and his family moved because of an important project. "I wondered why the postmark was from Hanford, and not White Bluffs. I learned that the families were asked not to mention much to their sons serving in the war" (Sorenson 1999).

For some, the enforced relocation came at a very high price: "It was a pretty hard thing. Some of them ended up at Medical Lake (the location of a state mental hospital), you know, they couldn't quite face it. My mother never really adjusted to it. The fact that the government could come in and take your home away" (Ashton 1999).

The Army used many of the abandoned homes for offices and living quarters and brought in prison labor to harvest the crops. Under condemnation, the government offered only the value for the home as assessed by non-local appraisers and not the value of improvements, equipment, or the crops in the field (Heriford 1995). Many landowners rejected the Army's offer and filed petitions in court to secure a better appraisal. "Matthias adopted a strategy of settling out of court to save time, time being a more important commodity than money to the Manhattan Project" (Gosling 1999, p. 32).

When they were done with construction of the Manhattan Project at the Hanford Site, the Army razed the homes and cut down the orchards. While the people were proud of what they had contributed to the war effort when "the secret" was revealed in 1945, their resentment over how they were treated remains strong even today. "Gone are those peaceful autumns; gone, in fact, is White Bluffs itself. It cannot even be called a ghost town, because the buildings too are gone, except for the remains of a few foundations which stand like teeth whose fillings have dropped out…White Bluffs was a victim of the age of the atom; it is a ghost which marks man's "progress" (Harris 1972, p. 1).

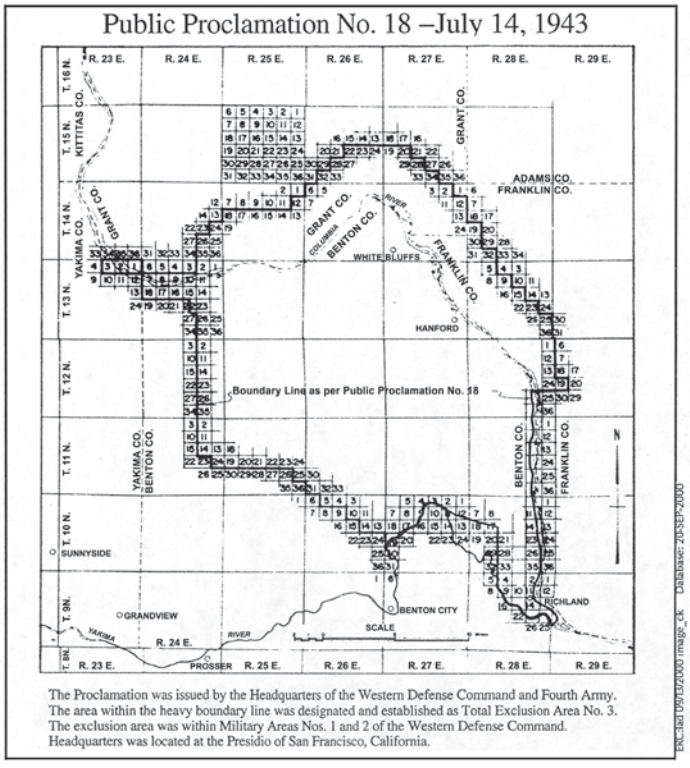


Figure 1.3. *Initial Map Designating the Area of the Hanford Site, 1943*

Findlay and Hevly (1995, p. 11) offer a less personal but more encompassing summary of the displacement of the local population: "The Army separated almost all people from their homes and lands on the site; only a handful of people, who got work on the project, stayed behind in their homes, and they now paid rent to Du Pont for the privilege. Even the dead were evicted. The government exhumed 177 burials from the White Bluffs cemetery and reinterred them in the nearby town of Prosser."

For the record, the Hanford townsite cemetery was also relocated to Prosser. The Army's actions at White Bluffs and Hanford were similar to those undertaken at Kingston and Clinton, Tennessee. There the Army acquired clear title for immediate use of approximately 56,000 acres between October 1942 and March 1943 through condemnation. Nearly 1000 families were forced to relocate, some within 2 weeks of receiving their eviction notice. Compensation came only after the property had been vacated, and relocation expenses were not compensated. There too, structures not retained for "war-related uses" were demolished (Souza et al. 1996, p. 3-35).

INITIAL CONSTRUCTION

Site Name:	Hanford Engineer Works - December 1943 to December 1946
Site Manager:	Col. Franklin T. Matthias - February 1943 to August 1945
Responsible Agency:	U.S. Army Corps of Engineers - December 1942 to December 1946
Site Contractor:	E. I. Du Pont de Nemours and Co, Inc. - December 1942 to August 1946

Groves succinctly recounts the rules common to all Manhattan Project construction sites: "All design was governed by three rules: 1) safety first against both known and unknown hazards; 2) certainty of operation – every possible chance of failure was guarded against; and 3) the utmost saving of time in achieving full production" (Groves 1983, p. 83).

The initial construction phase for the Hanford Engineer Works (originally named the Gable Project by the War Department and later named the Hanford Site) extended from March 1943 to February 1945 (Gerber 1992b). During that time, the Corps transformed an open agrarian landscape into a closed military-industrial complex described by one former resident as "a vast impersonal government site…with guards stationed at strategic points" (Harris 1972, pp. 1-2).

Chosen as much for its isolation as its resources of water, sand, and gravel, the Corps now had to construct not only the complex itself, but the infrastructure necessary to support it. That they did this under adverse conditions (particularly wind, weather, and a short labor supply) during wartime and under tight security was a major engineering accomplishment: "Once the land was procured, construction proceeded at a nearly unbelievable pace. In just the 30 months between groundbreaking in March 1943, and the end of the war in August 1945, the MED built 554 buildings not dedicated to living requirements" (Gerber 1992b, p. 6).

These buildings ranged from reactors, separation plants, and laboratories to craft shops, warehouses, and electrical substations. Many of these buildings, such as the reactors and chemical separations plants, were first-of-a-kind since nothing of their type or scale had ever existed before (see Sections 3 and 4 in Chapter 2 for expanded discussions). For comparison, Fermi's first "pile" (the Chicago Pile 1 Reactor or CP-1), designed only to demonstrate a sustained chain reaction, was an ellipse that measured 25 feet wide by 20 feet high and used 56 tons of uranium fuel, 400 tons of graphite, had no cooling system, and operated at a maximum power level of 200 watts-thermal. The X-10 Reactor at the Clinton Engineer Works, designed as an experimental reactor to provide research quantities of plutonium, was a 24-foot cube, used milled uranium-metal fuel elements encased in aluminum, was air-cooled, and operated at a maximum power level of 4 million watts-thermal. The Hanford Site Manhattan Project reactors (B, D, and F), designed as plutonium production plants, were rectangular, measured 36 feet long by 28 feet wide by 36 feet high, used 200 tons of uranium-metal fuel, used 1200 tons of graphite, were water-cooled, and operated at an initial power level of 250 million watts-thermal.

While the million-fold scale-up in reactors was remarkable, the Hanford Site chemical separations plants (221-B, 221-T, and 221-U) truly amplified the extant model developed at the Metallurgical Laboratory: "Plutonium production at Hanford depended as much on chemical separation as it did on chain-reacting piles [reactors]. The chemistry was Glenn Seaborg's, spectacularly scaled up a billionfold directly from his team's earlier ultramicrochemical work" (Rhodes 1986, p. 603).

Just as the selection of the Hanford Site had been preconditioned by siting criteria, so too was the design of the complex itself. The Corps and Du Pont used both the available space and the natural landforms to isolate and contain the primary production areas (see Figure 1.4). The reactors, six of which were planned, had to be adjacent to the Columbia River because of their cooling requirements. Starting inland from the western boundary and farthest from the communities of Richland, Kennewick, and Pasco, the reactors would be sited at intervals of at least 1 mile along the river. The reactor complexes were given sequential alphabetic identifications A through F. To increase separation between reactors and their isolation within the Hanford Site, the Corps selected B, D, and F as the initial locations for construction. By using alternating locations, the separation between reactors averaged nearly 6 miles. The reactor complexes were assigned the Area identification codes 100-B, 100-D, and 100-F. Each area (B, D, etc.) contained one reactor and support facilities.

The chemical separations plants, four of which were planned, would be built some 10 miles south of the reactors within the interior of the Hanford Site. Two of these plants would be built in the 200 East Area, while the other two would be built some 4 miles away in the 200 West Area. The basalt landforms of Gable Butte and Gable Mountain lay between the reactors and the separation plants, providing additional safety should something happen at either the irradiation or separation plants. Finally, the fuel manufacturing facilities (300 Area), considered the least threatening of the primary operations, would be located on the river approximately 20 miles southeast of the separation plants and 10 miles north of the administrative area (700 Area) and residential/commercial center (1100 Area) planned for Richland (Gerber 1994a, Gosling 1999, Rhodes 1986).

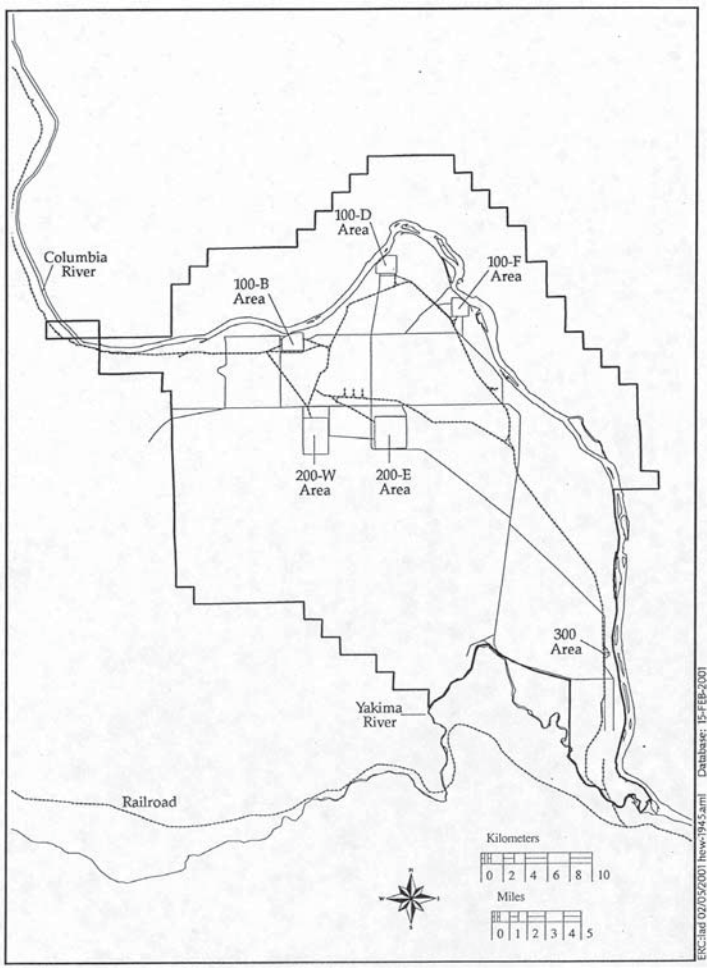


Figure 1.4. *Hanford Site during the Manhattan Project Around 1945 When the Site Was Called the Hanford Engineer Works*

The uncertainties surrounding the emerging technologies and the consequences associated with their failure marked the Hanford Site as one of the greatest scientific experiments of modern time or one of the riskiest. The Corps therefore designed each process area as an independent unit complete with operations facilities, operations support facilities, and administrative, security, health, communication, utility, and waste support facilities. This structural redundancy was a hedge against failure in any one unit since the overriding objective was the uninterrupted production of plutonium. To knit these units together, the Corps established a transportation, utilities, and communications infrastructure.

The single railroad line to the Hanford Site and the existing road system constituted the backbone of the transportation system that would move workers and

materials. However, these facilities needed to be upgraded. New construction added "158 miles of railroad and 386 miles of roadway" (Chatters 1989, p. D.85).

Electrical power for the 100 and 200 Areas would be obtained from the Grand Coulee-to-Bonneville grid, while the remainder of the Hanford Site would receive power from the Midway-to-Walla Walla tie-line. To route this power, the Corps constructed 52 miles of transmission lines. These electrical lines, together with the "distribution substations, fence and road lighting, fire alarm systems, and telephones and telephone cables," were a non-geographic area but nonetheless assigned a numeric area identification, the 500 Area, to meet the military need for order and organization (Gerber et al. 1997, p. 5.22).

Similarly, the 800 Area referred to the steam power plants and all "overhead pipe line facilities, specifically all pipe supports, steam lines, air lines, and process lines," while the 900 Area identified all "underground pipe line facilities, specifically the export water lines and valve houses, raw water and fire protection lines, sanitary sewers, process sewers, wells, and pumps" (Gerber et al. 1997, p. 5.23).

One of the most visible and ubiquitous items constructed was fencing. Hundreds of miles of fences were placed around the Hanford Site and its facilities. Fences were erected around key facilities within fenced complexes, and even the administrative center within the residential community was enclosed by fences. See Chapter 2, Sections 1 and 11, for additional discussion on construction and infrastructure.

RECRUITING A WORKFORCE AND SECURING MATERIALS

Recruiters made direct inquiries to Du Pont staff engineers, scientists, and consultants and enticed many to relocate with offers of better pay or more challenging work, although the specific nature of that work could not be explicitly stated (DeJong 1995). Du Pont, working with the War Manpower Commission and the U.S. Employment Service, conducted aggressive advertisement campaigns in 47 of the 48 existing states as well as Alaska and Canada. Tennessee was excluded because of recruitment for the Clinton Engineer Works. The advertisements touted "attractive" wages and extended, steady hours for skilled and unskilled workers. Unskilled workers could make twice the daily rate offered to laborers elsewhere, while skilled labor was offered a daily rate of $15 – 50 percent more than the prevailing rate of $10. Even with these incentives, maintaining a full labor force remained more an objective than an accomplishment throughout initial construction: "The work proceeded slowly, dogged by recruiting problems. The nation at war had moved beyond full employment to severe labor shortages and men and women willing to camp out on godforsaken scrubland far from any major city were hard to find" (Rhodes 1986, p. 499).

Recruiters had to work hard since "they found themselves competing against other employers, including the armed services, which enjoyed a head start in mobilizing for war" (Findlay and Hevly 1995, p. 15). To counter the effects of the draft and voluntary military enlistment, Du Pont reached out to people who were not at the top of the Selective Service's list: "Slightly more than half of all employees were 38 years or older, and therefore above the maximum drafting age, and three-quarters of those between 18 and 26 years old had 4-F ratings" (Findlay and Hevly 1995, p. 17). Women made up nearly 13 percent of the workforce, and African Americans made up an additional 16 percent. Both of these groups were segregated within the Hanford construction camp. While initially reluctant to hire Hispanic Americans, Matthias eventually conceded to the War Manpower Commission but housed those who were hired "near Pasco, off the Hanford Site and away from the other workers" (Findlay and Hevly 1995, p. 18).

Extraordinary measures were taken as necessary to ensure that construction continued at an accelerated schedule: "Later in 1944, when the project required trained pipe-fitters for completing the three piles [reactors], the Manhattan Engineer District (MED) furloughed enlisted men from active duty, enrolled them in reserve units, and employed them as civilian workers at Hanford, with a promise to reinduct them into the Army if their work proved unsatisfactory. Matthias and Du Pont protected other highly skilled personnel, which the project could not afford to lose, by reaching agreements with local draft boards" (Findlay and Hevly 1995, p. 16).

As with all aspects of the Manhattan Project, the need for secrecy hampered Du Pont's ability to hire and maintain workers. Since they could not be told specifically what the purpose of their work was, many employees left because they felt they were "not making a contribution to the war effort." Even those who stayed developed "a transient mentality" because they did not know if the Hanford Site would exist after the war. Union relations were difficult because of the secrecy issue although appeals to patriotism and skilled labor shortages "forced organized labor to become accommodating" (Findlay and Hevly 1995, p. 21). See Chapter 2, Section 12 for additional discussion of this topic.

The issue of secrecy extended to the acquisition of supplies. So as not to tip off the War Production Board, the Hanford Site was constrained by procurement and transportation ratings of less than the optimum AAA. Gerber (1992b, p. 11) notes, for example, materials such as "lower grades of steel, and even of earthenware" sometimes were substituted where "a high grade of Colombian (Austenitic) stainless steel" should have been used. Other materials like "heavy-gauge railroad track, cement, copper, lumber, iron, electrical wire, graphite and aluminum were always in short supply…[but] the Hanford project could acquire an overriding priority when necessary."

HANFORD CONSTRUCTION CAMP

Colonel Matthias was charged with delivering plutonium to Los Alamos as soon as possible, and Lieutenant General Groves made several visits to the Hanford Site to remind him of the urgency. Yet for most of 1943, Matthias had to postpone construction of the production facilities and concentrate the workforce on constructing the facilities needed to house and support the workers, most of whom lived in tents through the first 6 months of construction (Findlay and Hevly 1995). Du Pont selected the now evacuated Hanford townsite to serve as the genesis of the construction camp because of its proximity to the 100 and 200 Areas and the utilities already existing there. Already numbering 12,500 in August 1943, the construction force increased nearly four-fold to 45,000 at its peak in June 1944 (Thayer 1996). By that time, the "self-contained town" had "131 barracks for 24,892 men and another 64 barracks for 4,357 women; 880 hutments [Quonset huts] for men; and 3,639 trailer lots" (Findlay and Hevly 1995, p. 25). In addition to housing, the camp also included 65 construction shops, a 24-building administrative area, eight mess halls, saloons, stores, a recreation hall and auditorium, a theater, a bowling alley, and a softball diamond among other amenities. Services included eight schools, a day nursery, five fire stations, and a large infirmary and clinic (Gerber 1999, p. 5).

Rhodes (1986, p. 499) reports that meat rationing, common during the war, did not occur at the Hanford construction camp. In fact, the ready availability of meat was used in recruiting the workforce, which was amply fed as evidenced by the information obtained from a posting found on a barrack wall by Artie McDaniels. A copy of the posting is on file at the Library of the U.S. Department of Energy's Hanford Cultural Resources Laboratory in Richland, Washington (see sidebar box).

Various authors have described the Hanford construction camp as a "sea of tents and barracks, where workers had little to do and nowhere to go" (Gosling 1999, p. 32), where "boredom and loneliness" prevailed (Chatters 1989, p. D.85), and even the saloons were built "with windows hinged for easy tear-gas lobbing" (Rhodes 1986, p. 499). Findlay and Hevly (1995, p. 26) seek to put this "notoriety" in perspective by observing that the camp was not dissimilar from "the kind of rough-and-tumble community – like mining, lumber, and other construction camps – that emerged in the American West whenever a hard-working, well-paid, heavily male population was concentrated temporarily in one spot."

Just to be sure, however, the Corps did lock up their women, who lived in segregated barracks behind barbed wire under the watchful protection of "housemothers" and guards. The effectiveness of this enforced separation may be suspect, though, given events at Los Alamos where one women's dormitory came under review for closure until "a determined group of bachelors argued even more persuasively against closing the dorm. It seems that the girls had been doing a flourishing business of requiting the basic needs of our young men, and at a price" even with roving military police (Robert Wilson, quoted in Rhodes 1986, pp. 566-567).

A more typical image of life at the camp is provided by Susanna Brown, who together with her husband, moved to the Hanford Site from Texas in 1944: "Primer and I lived in different barracks with fences and a guard you had to show a pass to, going in and out. I worked the late shift and my husband worked on another so we didn't see much of each other. Primer would visit me in the sitting room – all of the women's barracks had one" (Sorenson 1996, p. 5).

Chapter 2, Section 12 of this book adds substantially to these images of life not only at the Hanford Camp but also throughout the operational life of the Hanford Site. It gives voice to the people who worked here and the issues they faced.

World War II Posting Found on a Barrack Wall

- 1,000,000 meal ticket cards on file
- $3,500,000 worth of meal tickets sold in 8 months through payroll deduction (does not include meal tickets sold for cash)
- Menus prepared 60 days in advance
- Eight mess halls, 2700 workers in each hall at each setting, usually three settings per meal
- 3000 pounds of sausage used for one breakfast
- 2500 pounds of pot roast for one meal
- 18,000 pork chops for one meal for one mess hall
- 11,000 pounds of Swiss steak for one meal for all mess halls
- 250,000 pounds of meat used for all mess halls for 1 week
- 15 tons of potatoes for one mess hall each day
- 5000 heads of lettuce for each meal for one mess hall
- 1200 pounds of onions for one meal for one mess hall
- 900 full pies for one meal for one mess hall
- 600 gallons of ice cream a day
- 250 good cows needed to supply the milk for one breakfast
- 1000 pounds of coffee for one day for one mess hall
- 700 cases of Coca-Cola a day
- 2200 loaves of bread used each day for sandwiches, not counting bread on tables
- Three sandwich machines, each making 360 sandwiches an hour
- 272,000 pounds of processed meat, ready for oven or grill used in 1 week
- 4,000,000 lunch boxes sold from July 1943 to October 1944
- 30,000 doughnuts for one day
- An automatic doughnut machine making 18,000 doughnuts per hour
- 6500 eggs used for Sunday breakfast (only time fried eggs could be served because meals were served over a longer period of time)
- 12,000 turkeys for Thanksgiving (22 tons of turkey, 12 tons of ham)

Other information supplied on this sheet indicates:

- Number of employees quartered in barracks: 40,000
- Number of employees quartered in trailer camp: 8,000
- 10,000 newspapers sold each day by recreation halls
- 16,000 packages of cigarettes sold each day
- 12,000 gallons of beer consumed each week (13 carloads)
- 2000 keys for barracks lost each month by employees
- 1,785,000 sheets washed. If these were tied together they would reach from Hanford to New York City
- Hanford is the largest voting precinct in the United States
- Hanford has the largest general-delivery post office in the world

From the beginning the workweek was long, and, as deadlines neared, it only got longer. It was initially a 6-day, 8-hour shift, then the Corps added an extra hour to each day in September 1943 and finally added floodlights to allow "around-the-clock construction" at the 100-B and 100-D Areas (Gerber 1992b, p. 8). Despite the cold and heat and the winds that blew the freshly released desert sands into and over everyone and everything, the workforce housed at the Hanford construction camp succeeded in building the world's first industrial-scale plutonium production and extraction complex in just under 2 years – a truly remarkable feat considering that today the paperwork alone required to permit construction of a single reactor would take significantly more time. By late February 1945 as the Corps and Du Pont were gearing up for operations, the camp was abandoned. Facilities that could be used elsewhere were moved out. Trailers, for example, were relocated to North Richland in 1946 to house General Electric and Atomic Energy Commission employees and their families, while the larger buildings such as the mess hall, recreation hall, and barracks were either dismantled or relocated to meet a growing postwar need for housing and temporary office space (Chatters 1989, p. D.85). Within a year after the war ended, whatever remained of the camp was removed and the area leveled, leaving only the roadway grid and a few isolated foundations low enough to have escaped complete destruction by the bulldozer's blade.

RICHLAND VILLAGE

Though construction began on both the Hanford construction camp and the Richland Village (1100 Area) in 1943, the areas provide a study in contrasts. "Du Pont built the Hanford camp to house the workers during construction of the first three production reactors, two chemical separations canyons, and assorted other facilities. It erected the Richland Village to house the employees who would administer and operate the plant" (Findlay and Hevly 1995, p. 12). The authors go on to list a number of juxtapositions beginning with their designations: Hanford was a camp, Richland was a village. Hanford was meant to last only as long as construction required, Richland would be a permanent settlement. Hanford was hastily built, Richland was planned and revised with changing conditions. Hanford was working class, Richland was middle class. Indeed, Matthias fully intended that Richland Village house supervisors, engineers, operators, and essential office staff and that craftsmen and laborers would be assimilated within the communities of Kennewick and Pasco.

To build the administrative and residential center, the Corps condemned the original Richland townsite and farms adjacent to it. Since the Hanford construction camp held a higher priority in terms of completion, residents of Richland were given until November 15 to evacuate their homes. As with the communities of White Bluffs and Hanford, the Corps identified 150 houses it could use together with some commercial properties and the irrigation system, then destroyed the rest creating an open, dusty landscape where the town once stood. While agreeing in principle that the Village would serve the managers and operators, the Corps and Du Pont disagreed on how well and at what cost. Groves ordered that Richland Village be built "as cheaply as possible" and pressed the same requirement on Los Alamos and the Clinton Engineer Works. However, Du Pont, in effect looking out for its future staff who would be the operators and managers of the Hanford Site, insisted that quality and comfort be included within the design. For example, while Groves proposed "barracks and dormitories," Du Pont held firm for houses and submitted designs commensurate with the employee's status – the alphabet houses that still distinguish the former Richland Village within contemporary Richland. Unlike Los Alamos and the Clinton Engineer Works, Richland Village was not enclosed within a fence, although it was tightly guarded and monitored by the Army. The only fenced area within the Village included the Administrative or 700 Area (Findlay and Hevly 1995, p. 34-39).

> ***"When completed, wartime Richland represented a compromise between the visions of Du Pont and Groves. As a result of the general's efforts to economize, the town wound up with inadequate numbers of sidewalks, garages, stores, and shopping areas, no civic center, and roads too narrow for much auto traffic…Wartime Richland also had its share of temporary housing – 25 dormitories by 1945 – so that it could house both construction and operations personnel when those two phases of Hanford's development overlapped."*** **- Findlay and Hevly 1995, p. 38**

G. Albin Pehrson, the Spokane architectural engineer Du Pont engaged to design Richland Village, developed a "neighborhood-oriented plan" that would provide an "island of refuge" from the military atmosphere surrounding the Hanford Site. By 1945, the Village contained 4329 houses and a population of 16,000. The houses, eight conventional styles (A, B, D, E, F, G, H, and L) and three pre-fabricated styles (A-1, B-1, and C-1), were classified based on the number of bedrooms and total cost (Gerber et al. 1997, pp. 5.24-5.25). For the few who moved from the construction camp to the Village, the difference was described by Nell MacGregor: "We felt unspeakably elegant in rooms with plastered walls, painted woodwork and splinterless floors" (Findlay and Hevly 1995, p. 34).

Richland Village also contained 24 commercial or retail stores including food and drug stores, barber and beauty shops, a hardware and variety store, and an icehouse. Community buildings included three schools, a church, a hospital, a movie theater, and a combined police and fire station. Recreational activities were enhanced by the incorporation of open spaces and green belts within the residential areas and a park along the Columbia River (Gerber et al., 1997, p. 5.25). Interestingly, in an ironic way, Du Pont and the Army found themselves on opposing sides with respect to the operation of the Village:

> *"In building Richland, the Army had wanted to skimp on expenses while Du Pont had wished to spend more; in operating the village, those roles were reversed. W.O. Simon, Du Pont's manager at HEW, called the Army "liberal" in its treatment of residents and pointed out a number of instances where the Army had demonstrated too much initiative in providing services to townspeople. Du Pont's more "conservative" approach, according to Simon, "would avoid any activity or endeavor not necessary to its immediate needs and would follow rather than anticipate public opinion."* - Findlay and Hevly 1995, p. 43

Anytime the Army is called "liberal," a significant difference of opinion must exist. Engaging as this thread may be, the interested reader is directed to continue with the Findlay and Hevly manuscript for a better understanding of the cultural history of the Hanford Site and the Tri-Cities.

CONSTRUCTING THE OPERATIONS FACILITIES

Construction of the operating facilities was a shared responsibility among the Corps, the Metallurgical Laboratory, and Du Pont. The Corps was responsible for funding, scheduling, and decision making. The Metallurgical Laboratory scientists were responsible for the theoretical construct. Du Pont was responsible for design and engineering. As with many multiparty undertakings, the degree to which the parties disparage one another varies inversely with the level of success being achieved. In this case, the scientists were quick and consistent in criticizing Du Pont's "caution, expertise, and management skills," though in hindsight many credit Du Pont's "industrial experience, its engineering orientation, and its cautious policies" with bringing order to chaos and ultimately ensuring "the timely success of Hanford" (Findlay and Hevly 1995, pp. 13-14). Groves singles out Du Pont manager Crawford H. Greenewalt for praise in handling a difficult situation:

> *"[Greenewalt] served as the bridge between the hard-driving, thoroughly competent, industrial-minded, scientific engineers and executives at Wilmington and the highly intelligent and theoretically inclined scientists at Chicago. This means that he had to shuttle back and forth between Chicago and Wilmington and later Hanford, easing tensions and calming tempers and, at the same time, seeing to it that needed scientific decisions were promptly reached at Chicago."* - Groves 1983, p. 79

Gosling (1999, p. 30) maintains that a sense of lessened importance, occasioned by the construction of the Hanford Site and the Clinton Engineer Works, fueled some of the scientists' criticism as "Met Lab research became increasingly unimportant in the race for the bomb and the scientists found themselves serving primarily as consultants for Du Pont." Time, or more specifically the lack of it, was also a factor: "The scientists' complaint about Du Pont, and General Groves' constant pressure on Matthias, stemmed primarily from the extreme urgency of the project from start to finish…Such urgency pushed construction and operations at Hanford at a pace that would have been inconceivable outside of wartime" (Findlay and Hevly 1995, p. 14).

Uncertainty coupled with accelerated schedules contributed even more to the frustration of all parties. Construction would be ongoing while the basic research underlying nuclear reaction and chemical separations was still being developed. However, as Groves later noted, "it is essential to keep in mind the truly pioneering nature of the plutonium development…gigantic steps [were taken]…moving rapidly…from the idea stage to an operating plant" (Groves quoted in Gerber 1992b, p. 11).

Design and construction proceeded simultaneously and more often than not out of step since the exigencies of war allowed little or no time for testing or validating designs. For example, groundbreaking for the cooling system for the first Hanford Site production reactor, 105-B, began on August 27, 1943, barely 8 months after Fermi had started CP-1, a short-term experimental reactor operated with no cooling system, and 3 months before initial operation of the air-cooled X-10 Reactor. Cooling a reactor with water was unprecedented, yet the success of full-scale plutonium production and the Hanford Site's contribution to the Manhattan Project in large part rested on this entirely new and untested technology: "Because of the tremendous energy associated with fission, a great amount of heat is developed. To produce one ounce of plutonium, the reactor must develop a thousand kilowatts of heat power for a period of a month. Where many pounds are involved, a major engineering problem is the removal of this heat" (Compton 1956, p. 161).

On October 4, 1943, Du Pont engineers released the design drawings for the B Reactor allowing construction to begin 6 days later with general site preparation (Sublette 1997). "Starting with the foundations for the pile [reactor] and the deepwater basins behind it where the irradiated slugs [fuel elements] would be collected after discharge, the work crews were well above ground by the end of the year" (Rhodes 1986, pp. 499-500). See the Historic American Engineering Record (HAER) for the B Reactor in Appendix B of this book on the Internet for a detailed discussion of the reactor's construction and operations.

More than half a continent away, Du Pont was also constructing the X-10 complex at the Clinton Engineer Works to test the principles of reactor operation and plutonium separation. Groundbreaking on this pilot reactor and its associated chemical separations plant containing six hot cells had begun during February 1943. Within 9 months of initiating construction, the X-10 Graphite Reactor went critical (condition in which a material undergoes nuclear fission at a self-sustaining rate) on November 4, 1943 and began "producing the first substantial (gram) amounts of plutonium to assist research into its properties" (Sublette 1997). With the world's supply of plutonium at this time standing at 2.5 milligrams, all produced in cyclotrons, the 1.54 milligrams extracted within the separation cells at the Clinton Engineer Works by the end of the year nearly doubled the amount available for research. A secret courier carried the plutonium to the Metallurgical Laboratory in Chicago using a container resembling a penlight (Souza et al. 1996, p. 3-39). Although this air-cooled experimental reactor was not a true prototype, experience gained in its construction assisted Du Pont's efforts with the Hanford Site reactors. The Hanford Site benefited from the X-10 reactor in other ways as well. Before June 1944, Du Pont sent future Hanford Site reactor operators to the Clinton Engineer Works for on-the-job training.

As noted earlier, security and secrecy were hallmarks of the Manhattan Project. This extended even to the blueprints used in constructing critical buildings. As described in the B Reactor HAER in Appendix B on the Internet, Rudy DeJong, a construction foreman at the B Reactor, recalls that the "foremen, engineers, and superintendents were the only ones who ever saw a drawing! We had to go into a vault inside the reactor building, look at the drawings, figure and get your dimensions, make notes, then go out to your crew and tell them what to do and what your dimensions were!" Du Pont also, for security reasons, designated the reactor buildings "classified" and further restricted worker access to those possessing the proper badge. A separate division engineer supervised construction of the reactor buildings. This helped maintain "compartmentalization," which was the heart of security and secrecy. Compartmentalization, as Groves established it, meant "each man should know everything he needed to know to do his job and nothing else" (Groves 1983, p. 140).

Fewer than one percent of the workers were told the true nature of the project. One who was briefed, Kenneth McCreight, a supervisor in charge of over 1800 electricians, remembers some very long workdays extending 18-20 hours and switching assignments or terminating workers when necessary if too many questions were asked. He

"hand picked" workers for the reactors and "the ones who were less skilled or couldn't get along with others" were assigned "less sensitive work such as building offices and septic systems" (Gerber 1994b, p. 16).

In addition to the three 100 Area reactor complexes along the Columbia River, Du Pont also constructed three chemical separations complexes within the interior of the Hanford Site. The 200 West Area contained the 221-T and 221-U Plants, while the 221-B Plant was located in the 200 East Area. The second separations plant (221-C) planned for the 200 East Area was cancelled when Groves determined it was unnecessary based on experience and information gained from operations at the Clinton Semiworks (Gerber et al. 1997). Indeed, only the 221-B and 221-T Plants were operated during World War II although Du Pont had constructed all three by early 1945. Gosling (1999, p. 33) observes that "labor shortages and the lack of blueprints" so constrained construction activities in the 200 Areas that Du Pont redirected workers to the 100-B Area "with the result that the 1943 construction progress on chemical separations was limited to digging two huge holes in the ground."

The Hanford Site chemical separations plants (locally called "canyons" because of their architectural design featuring a very long, high-walled, windowless operations area) dwarfed the pilot plant built at the Clinton Engineer Works. The Clinton Semiworks contained six hot cells, while the process plants on the Hanford Site contained forty. Measuring more than 800 feet long, 65 feet wide, and with a surface height of 80 feet (an additional 20 feet lay below grade), the workers also nicknamed the buildings "Queen Marys" after the British ocean liner. Stark, nearly featureless concrete structures on the outside, "the interior had an eerie quality as operators behind thick concrete shielding manipulated remote control equipment by looking through television monitors and periscopes from an upper gallery" (Gosling 1999, p. 34). To protect process workers from intense radiation, Du Pont engineer Raymond P. Genereaux designed each process cell to be encased within concrete walls 7 feet thick and enclosed each cell with a 6-foot-thick cover weighing 35 tons. A traveling overhead crane was used to lift the covers when necessary (Gerber et al. 1997).

> ***"Once the Queen Marys were contaminated with radioactivity no repair crews could enter them. Equipment operators had to be able to maintain them by remote control. The operators trained at Du Pont in Delaware, at Oak Ridge and on mockups at Hanford, but the engineer in charge…sought more authoritative qualifications. And found it: he required his operators, one hundred of whom arrived at Hanford in October 1944, to install the process equipment into the first completed separation building by remote control, pretending the canyon was already radioactive. They did, awkwardly at first but with increasing confidence as practice improved their remote-manipulation skills." -*** **Rhodes 1986, p. 604**

To receive the high level radioactive liquid wastes (radioisotopes and chemicals) resulting from the chemical separations process, Du Pont constructed 64 single-shell underground storage tanks in four complexes (241-B, 241-C, 241-T, 241-U), known as "tank farms." Each complex consisted of sixteen tanks – twelve 500,000-gallon tanks and four 54,500-gallon tanks (Gerber 1992b). Each of the 500,000-gallon tanks measured 75 feet in diameter and was constructed of "reinforced concrete with a one-fourth inch welded [carbon-] steel plate lining" (Gerber et al. 1997, p. 5.83). The four smaller tanks were 20 feet in diameter. Gerber (1992c, p. 46) reports that by the end of the Manhattan Project "half of these tanks were 100 percent full and the other half were 40 percent full." This is understandable given the fact that nearly 10,000 gallons of high level radioactive waste was generated per day at both 221-T and 221-B Plants (Anderson1990).

Stretching the workforce even further, Du Pont was also busy constructing the fuel manufacturing and testing facilities within the 300 Area. While irradiation and chemical separations were more visible steps in producing weapons-grade plutonium (based on the sheer number of facilities devoted to each of these operations), both were sequential steps that relied on precisely milled and processed uranium metal fuel elements, commonly known as "slugs." The 313 Metal Fabrication Building and 314 Press Building were key facilities that supplied the fuel elements for irradiation in the reactors.

Both the 313 and 314 Buildings were operational well before the reactors were completed because without fuel the reactors could not be charged. Completed in the fall 1943, about the same time that reactor construction began, the 313 Building was reconfigured with eight additions within a 10-month period, each addition responding to "process improvements and changes in the very new, untried, and unique uranium fuel fabrication activities being carried out in the facility" (Gerber 1993b, p. 1). In January 1945, workers at the 314 Building began to extrude (press) uranium billets (uranium metal cylinders approximately 20 inches long and weighing 200 pounds) into rods that machinists shaped into fuel elements in the 313 Building (DOE 1997e, p. 151). Prior to this onsite capability, the Hanford Site received pre-extruded uranium metal rods directly from outside sources beginning October 1943 (see Chapter 2, Section 2 for additional discussion and illustrations).

The 305 Test Pile (reactor), of necessity, was also constructed and operational before the production reactors in the 100 Areas. Beginning in March 1944, this 16-foot graphite cube, air-cooled, natural uranium-powered reactor, the first to operate on the Hanford Site, "compared the performance of material samples under irradiation with samples of known quality and graded each lot" (Gerber 1993b, p. 11). For example, to maximize the movement of neutrons, only very pure graphite could be used in constructing the production reactors. To ensure that suitable graphite was delivered to the 100 Areas, the 305 Test Pile was pushed to 16 hours a day almost as soon as it became operational. By May, it was testing graphite bars 24 hours a day. This schedule was maintained until August when operations were scaled back to a single 8-hour shift. In addition to graphite bars, the 305 Test Pile irradiated and tested uranium billets (called "eggs"), fuel elements, aluminum canning materials, aluminum welding rods, and aluminum process tubes. This reactor also provided a radiation source for developing and calibrating radiation detection and measurement instruments (Gerber1993b, pp. 11-13).

Like the 305 Test Pile, the 321 Separations Laboratory and the 3706 Radiochemistry Laboratory provided onsite research and trouble-shooting capabilities for the chemical separations process still under development as the 200 Area canyon buildings were being designed and constructed. Completed in December 1944, the 321 Building was a pilot-scale plant used "to replicate, study, and develop solutions to problems developed in the early bismuth phosphate chemical separations process used in Hanford's T Plant and B Plant" as well as "equipment corrosion studies and methods of decontamination" (Gerber 1993b, p. 15). The 3706 Building was the first radiochemistry laboratory at the Hanford Site. Completed early in 1945, researchers used the 57 laboratories "to perform small-scale experiments with both low- and high-activity radioactive materials in support of all HEW production activities" (Gerber 1993b, p. 19). The Historic Property Inventory Forms (HPIF) for the 305, 321, and 3706 buildings give more detailed discussions of activities, accomplishments, and architecture (see Appendix B on the Internet).

Construction of the Hanford Site was a massive undertaking. Simultaneously, Du Pont built three reactor complexes, two chemical separations complexes, a fuel manufacturing and research and development center, a construction camp, and an employee village. The B Reactor HAER in Appendix B on the Internet summarizes the comments made by a number of the people directly involved in constructing the Hanford Site (see sidebar box).

> ***"The work that was performed at the Hanford Site was of monumental proportions, rising from bare desert to fully functional industrial complex in a scant two years, while creating a nuclear technology that had only just been discovered. Even under peacetime conditions, the project would have garnered notoriety for its cutting-edge developments and, especially, its complete success. During the incredible push of wartime production and urgency, however, the story takes on legendary proportions."*** -
> **B Reactor HAER**

Each production complex was self-contained, complete with administrative, operational, health, security, maintenance, supply, and utility support facilities. This designed redundancy ensured that plutonium production would not be interrupted – an imperative for the Manhattan Project. A sense of the scale of construction, momentarily discounting its engineering complexity, is imparted through a summary listing of numbers alone. Within the 100 Areas, 94 permanent buildings and 69 service facilities were constructed. Additionally, "over 100 small support service TC [temporary construction] structures were built in each

100 Area including warming sheds, privies, check booths, miscellaneous sheds and guard/badge houses" (Gerber et al. 1997, p. 5.16). This number does not include the 50 or more temporary construction structures used for the Division Engineers Office, Government Field Office, Safety Office, Machine-Millwright and Sheetmetal Shop, and structures for other administrative and craft support. The 200 Areas contained 108 permanent buildings and 62 service facilities and an additional 100 temporary construction buildings and structures. The 300 Area contained 34 permanent buildings and 25 service facilities. Only seven temporary construction buildings are accounted for in the 300 Area, which is considerably fewer than the other Areas, "because more of the 300 Area work was done by subcontractors who provided their own facilities" (Gerber et al. 1997, p. 5.20). These numbers are further augmented by the 9 permanent buildings and 14 service facilities in the 200 North Area, the "machine shops, pipe and electrical shops and carpentry shops" constructed for site-wide support at White Bluffs (Gerber 1999, p. 4), the Hot Mix Plant, and the Riverland Classification Railroad Yard among other operational and support facilities outside the designated Areas (Gerber et al. 1997).

"IT'S ATOMIC BOMBS": HANFORD SITE OPERATIONS 1943–1945

On July 4, 1944, Oppenheimer informed the Los Alamos staff that the "neutron emission of reactor-produced plutonium was too high for the gun assembly to work" (Sublette 1999). The gun assembly required that two subcritical masses of the proper size and shape be forced together at high speed to obtain a supercritical mass that would initiate a chain reaction and subsequent explosion. Predetonation of either or both of the subcritical masses because of "spontaneously emitted neutrons" would render the bomb useless (Gosling 1999, p. 38). Given the rate of emission determined by Emilio Segrè, the planned plutonium gun had to be abandoned.

At this point in 1944, with construction of B Reactor nearly complete, the irony in Oppenheimer's announcement is sadly apparent: "The only workable bomb design at hand, the gun-type weapon, required U-235 which had no proven practical production methods available…Plutonium production had not yet begun, but the production technique appeared to have a high probability of success. However plausible approaches to building a plutonium bomb did not yet exist" (Sublette 1999).

Fortunately, Seth H. Neddermeyer of the ordnance staff at Los Alamos had been investigating an alternative, though highly theoretical, method for explosion with uranium of a purity less than optimal. These emergent studies were now directed to plutonium. Implosion would use high explosives to direct symmetrical shockwaves inward towards a subcritical mass of imbedded plutonium. The force of the explosion would compress the plutonium into a supercritical mass and initiate the chain reaction leading to explosion. Implosion research became a top priority. "With just 12 months to go before expected weapon delivery a new fundamental technology...had to be invented, made reliable, and an enormous array of engineering problems had to be solved" (Sublette 1999). Oppenheimer assigned the task to Neddermeyer and George B. Kistiakowski.

The unplanned change to implosion also had an impact on the Hanford Site. Even before they were operational, production rates would be accelerated to counter the uncertainty of how much plutonium would be required. Given Grove's directive to deliver as much plutonium as possible as quickly as possible, initial activation of the B Reactor did not bode well. First-person accounts of the Hanford Site operators' startup of B Reactor can be found in Sections 3.1-3.3 of the B Reactor HAER in Appendix B on the Internet.

Ten months after the X-10 reactor had gone critical, Enrico Fermi was present to witness the startup of the Hanford Site's B Reactor. On September 13, 1944, Fermi loaded the first fuel element into the reactor: "the Pope," says Rhodes (1986, p. 557), "conferring his blessing as he had on the piles [reactors] at Chicago and Oak Ridge." It took 2 weeks to hand load 1595 process tubes, slightly more than the 1500 calculated by Eugene Wigner in his initial design.

> ***"Tuesday evening, September 26, 1944, the largest atomic pile [reactor] yet assembled on earth was ready…The operators withdrew the control rods in stages just as Fermi had once directed at CP-1…The pile [reactor] went critical a few minutes past midnight; by 2 A.M. it was operating at a higher level of power than any previous chain reaction. For the space of an hour all went well…Early Wednesday evening B pile died…Early Thursday morning the pile came back to life. By 7 A.M. it was running well above critical again. But twelve hours later it began another decline. Princeton theoretician John A. Wheeler…had been "concerned for months about fission product poisons." B pile's heavy breathing convinced him such a poisoning had occurred."*** **- Rhodes 1986, pp. 557-558**

Wheeler suspected that xenon-135, a daughter product of the reaction-induced isotope iodine-135, was the neutron-absorbing poison that was causing the reactor to fail. Once this short-lived isotope had decayed, the reaction would revive and continue building until the xenon level increased to the point where it again began to absorb the neutrons necessary to sustain the chain reaction.

To determine if this were the case, Crawford Greenewalt, also present for the startup, called Samuel Allison at the Argonne laboratory to test Wheeler's theory using the CP-3 reactor: "Disbelieving, [Walter] Zinn started the 300-kilowatt reactor up again and ran it at full power for twelve hours. It was primarily a research instrument and it had never been run for so long at full power before. He found the xenon effect…Groves received the news acidly. He had ordered Compton to run CP-3 at full power full time to look for just such trouble" (Rhodes 1986, p. 559).

Extra reactivity would have to be added to overcome this effect before production could begin. Fortunately, and providing a concrete example of Du Pont's conservative engineering approach overriding the theoretical calculations of the Metallurgical Laboratory scientists, Wheeler had anticipated this chance of failure: "Wheeler had fretted about fission-product poisoning…[and] had advised the chemical company to increase the count of uranium channels for a margin of safety…That necessitated drilling out the shield blocks, which delayed construction and added millions to the cost. Du Pont had accepted the delay and drilled the extra channels. They were in place now when they were needed, although not yet connected to the water supply" (Rhodes 1986, p. 560).

It would take 2 months to connect the remaining 409 channels, thereby achieving the reactor's full design configuration of 2004 process tubes. In the interim, however, having benefited from Du Pont's earlier engineering decision, the D Reactor went critical on December 17, 1944, "with sufficient reactivity to overcome fission product poisoning effects" (Sublette 1999). By December 28, 1944, all work required at B Reactor was completed. With these two reactors operating in tandem, large-scale plutonium production was under way. When the F Reactor went on-line on February 25, 1945, theoretical production capacity from the combined reactors rose to 21 kilograms per month (Sublette 1997).

Nevertheless, initial production efforts at the Hanford Site remained tied to B Reactor. The B Reactor was not idle during the 2 months it took to supply cooling water to all 2004 process tubes. Between September 30 and December 28, the reactor operated intermittently at steadily increasing power levels while fuel was added and discharged and additional process tubes were connected to the cooling system. As described in the B Reactor HAER (see Appendix B on the Internet), a test run of irradiated fuel elements was discharged from a single process tube on November 6, 1944, "much earlier than would be normal for fuel processing [usually 100 days], but even mildly hot fuel was badly needed to test the various fuel-handling and chemical separations facilities in the 100 and 200 Areas."

The first scheduled discharge of 42 tubes took place between November 24 and 28. These fuel elements were transported by rail to the 200-North Area Lag Storage Buildings (212-N, 212-P, and 212-R) where they were allowed to cool. Within 30 days they were shipped to the T Plant where the world's first production-scale chemical separations processing began on December 26, 1944. Processing was complete on February 2, 1945. Colonel Matthias himself drove the first plutonium shipment from the Hanford Site to Portland, Oregon, then boarded a train for Los Angeles, where he delivered the product to an "agent from Los Alamos" on February 3, 1945 (Findlay and Hevly 1995, p. 50).

The B Plant came on-line on April 13, 1945. With this increased separations capacity, workers prepared a plutonium shipment for rail transportation every 5 days. To speed delivery, heavily guarded truck caravans replaced rail transportation beginning in May. To further accelerate delivery, Du Pont abandoned ground transportation and sent planes directly to Los Alamos beginning in late July. In the face of intense pressure from Oppenheimer in Los Alamos and Groves in Washington, D.C., Matthias continuously pressed Du Pont to produce more plutonium. In response, Du Pont not only "ran the reactors above their rated power level" (Findlay and Hevly 1995, p. 50), but also reduced the radiological cooling period for irradiated fuel elements to potentially unsafe levels to meet immediate demands: "Throughout the spring and early summer of 1945, metal cooling times fell, as HEW rushed to produce plutonium for the Trinity and Nagasaki bombs. Exactly how short the metal decay periods became is unclear, but it is known that they fell below 30 days and to perhaps as low as a few weeks" (Gerber 1994a, p. 1).

Even with accelerated production, Groves never let up and "continued to push for heightened production until the day Japan surrendered" (Findlay and Hevly 1995, p. 51).

PRODUCTION CYCLE

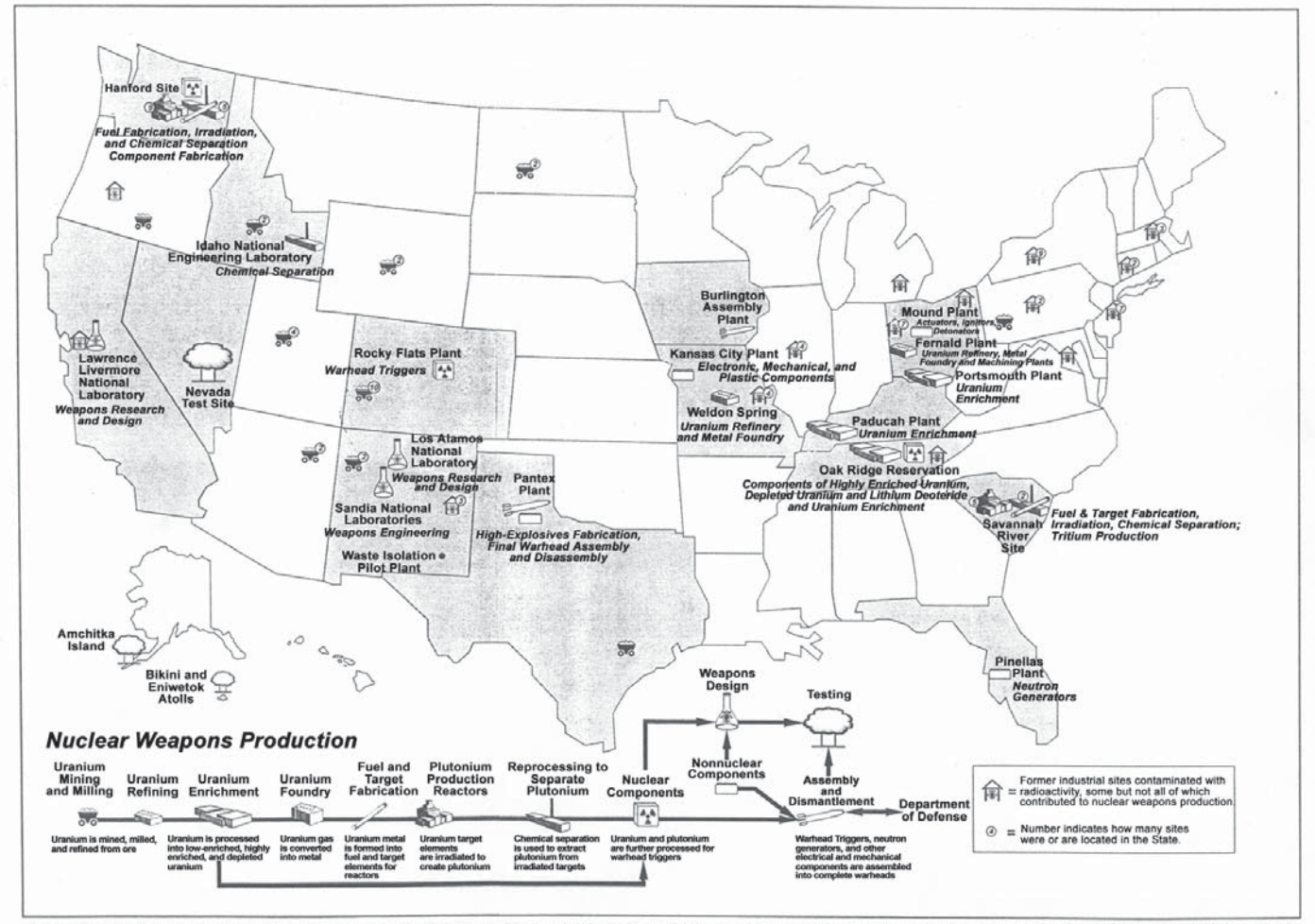
Much as Niels Bohr had surmised in March 1939, the production of nuclear weapons in the United States became "a complex series of integrated manufacturing activities executed at multiple sites across the country" (DOE 1997e, p. 117). The Hanford Site was one of only three Manhattan Project complexes built to develop the atomic bomb. Its mission, to produce plutonium, complimented that of the Oak Ridge Reservation, where enriched uranium was produced. Together, these two "production" sites supplied the scientists at Los Alamos with the nuclear materials necessary to test and fabricate the atomic fuels that powered the Fat Man and Little Boy bombs, respectively. After World War II, however, the Hanford Site, Oak Ridge Reservation, and Los Alamos became part of an expanding nuclear weapons complex that ultimately spanned the United States with facilities in 28 states (Figure 1.5). Most facilities were highly specialized, contributing key services or materials in the national production line. Examples include uranium mining in Wyoming, uranium refinement in Ohio, weapons assembly in Texas, and weapons testing in Nevada. No one facility could do it all, and none existed in isolation. This was the height of compartmentalization. Throughout its operational history, the Hanford Site remained a principal component of the U.S. nuclear weapons complex.

When writing the history of nuclear weapons production, DOE (1997e, p. 117) grouped production activities into eight major processes:

- Mining, milling, and refining of uranium
- Isotope separation of uranium, lithium, boron, and heavy water
- Fuel and target fabrication for production reactors
- Reactor operations to irradiate fuel and targets to produce nuclear materials
- Chemical separations of plutonium, uranium, and tritium
- Component fabrication of both nuclear and nonnuclear components
- Weapon operations, including assembly, maintenance, modification, and development of nuclear weapons
- Research, development, and testing

The Hanford Site played a part in five of these activities – fuel and target fabrication, reactor operations, chemical separations, component fabrication, and research and development. Component fabrication did not begin at the Hanford Site until 1949 with construction of the Plutonium Finishing Plant (234-5Z Building) where plutonium nitrate paste was further refined into plutonium metal (called "buttons") and machined into weapons parts (called "pits").

Figure 1.6 is a stylized presentation of the Hanford Site production cycle as it existed throughout the Manhattan Project. The cycle began with the arrival of uranium billets from offsite sources. These billets were pressed, machined, canned, tested, and stored in the 300 Area. From there, the unirradiated fuel elements ("fresh metal") were transported to the 100 Areas where they were irradiated within the reactors. Irradiated fuel "cooled" (a term for the decay of short-term radioisotopes) in the 200 North Area before being transported to the 200 East or 200 West Areas for separation within the chemical separations plants. Following separation and concentration, the plutonium, in the form of plutonium nitrate



The United States nuclear weapons complex comprised dozens of industrial facilities and laboratories across the country. The weapons production infrastructure originated with the Manhattan Project during World War II and evolved and operated until the late 1980s. It typically employed more than100,000 contractor personnel at any one time. From the Manhattan Project to the present, the United States has spent approximately $300 billion on nuclear weapons research, production, and testing (in 1995 dollars).

Figure 1.5. *U.S. Nuclear Weapons Complex*

paste, was returned to the 200 North Area for storage before being shipped to Los Alamos. Detailed accounts of these operations are presented in Chapter 2, Sections 2 through 4.

Fuel Manufacturing

The first essential step in the plutonium production process was to manufacture uranium fuel. From the time pre-pressed uranium metal rods began to arrive at the Hanford Site in October 1943, workers systematically increased the manufacturing operations on site. Millwrights began to machine extruded uranium rods in December 1943. Canning operations began in March 1944. By September 1944, workers began straightening and "outgassing" (a term for removing hydrogen and other gases) fuel rods on site. Uranium metal billets first arrived in November 1944. Machinists began to extrude fuel rods from these billets in January 1945 (Gerber et al.1997, DOE 1997e).

The following steps in the fuel manufacturing process are a composite, assuming uranium billets were the initial raw material, and all activities were conducted on site. When shipments of fresh metal in the form of billets first arrived at the Hanford Site, workers stored the billets in one of the nine 303 Buildings (303-A, B, C, D, E, F, G, J, and K) within the 300 Area. Inspectors selected samples for testing in the 305 Test Pile (reactor). Lots matching purity requirements were sent to the 314 Building to be heated within a furnace in an inert (argon) atmosphere then forced through a press to form rods from 12-14 feet in length. These rods were straightened and outgassed to ensure distortion did not occur within the

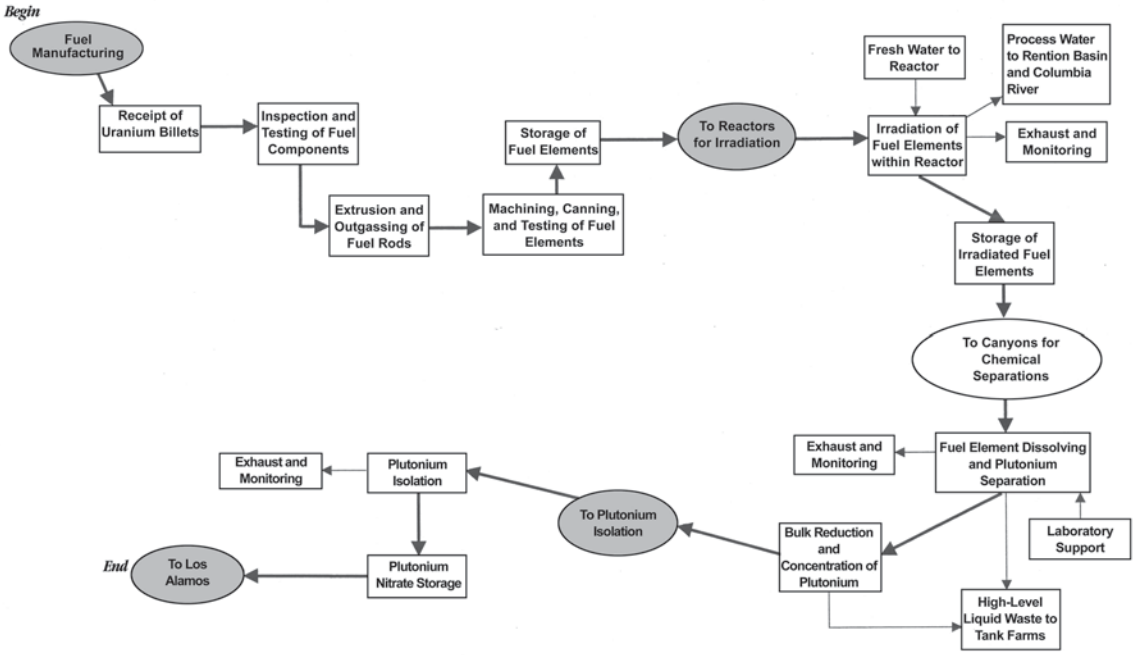


Figure 1.6. *Plutonium Production Cycle as It Existed throughout the Manhattan Project at the Hanford Site*

reactor. The rods were then sent to the 313 Building where they were machined (cut and turned) under very exacting tolerances to the required length and diameter. The cores (machined sections of rods) were "degreased" (dirt and oils removed in solvents) and "pickled" (solvent residue removed with an acid solution). The cleaned cores were then "canned" – a two-step process that involved preparing the core and inserting it within a sealed aluminum container. Short-lived electrical canning of cores began in March 1944.

The primary piece of equipment, an electric heater press nicknamed the "whiz bang," never performed well, and the entire process was replaced by the triple-dip method in August 1944. The fuel elements (canned cores) were subjected to three tests to ensure quality. Two of these, the Frost Test and Etch Test, were performed in the 313 Building. Each was designed to detect bonding or canning failures. The final test, steam autoclaving, was designed to detect leaks that would cause the fuel element to burst within the reactor. This test was conducted in the 314 Building. Every step had accompanying inspection points, and pieces not meeting rigorous standards were sent back for recycling. Chapter 2, Section 2 describes the fuel manufacturing process in detail.

Reactor Operations

Reactor operations included loading the fuel, operating the reactor, removing the fuel, and maintaining the reactor. It took 1 metric ton of uranium metal to produce 250 grams of plutonium. The movement of two key elements (water and fuel) is at the core of this second step in the production cycle.

The B, D, and F Reactors were designed as single-pass, water-cooled reactors. A continuous flow of water would pass through the reactors, absorbing and removing the heat generated by the nuclear chain reaction. In part, the Hanford Site was selected because the Columbia River afforded a near limitless supply of cold water. On the clean side of the reactor, the 108, 181, 182, 183, 185, 189, and 190 Buildings supplied and treated the water essential to operating the reactors. The 107 structures received heated process water flowing out of the reactors before its return to the Columbia River.

Water was withdrawn from the Columbia River through the 181 River Pump Houses located directly on the river. Electric pumps provided the power that pulled water from below the normal low-water level through the 181 Buildings and into the 182 Reservoir and Pump Houses. The 182 Buildings stored 25 million gallons of primary and secondary

(backup) water. Primary water was pumped to the 183 Filter/Treatment Plants, and secondary water was held in reserve for emergency situations. Within the 183 Buildings, raw water was purified with chemicals (mixed and supplied via the 108 Chemical Pump Houses), filtered to remove particulate matter, and stored for use in multiple "clearwells" – each with a holding capacity of 5 million gallons.

Throughout World War II, filtered water was then subjected to supplemental treatments that were later discontinued as unnecessary. In the supplemental treatments, dissolved gases, "particularly carbon dioxide and oxygen," were removed within the 185 Deaeration Plants to improve the "heat transfer capacity of the coolant" (Gerber et al. 1997, p. 5.78). An additional step was taken at the 100-D and 100-F Areas. Here, water was next pumped to the 189 Refrigeration Buildings where it was chilled "allowing the reactors to operate at higher power levels and still not heat the process water to the point where it would flash to steam" (Gerber et al. 1997, p. 5.33). Prepared water was then pumped to the Filtered Water Storage Tanks within the 190 Process Pump Houses. Pumps housed in the 190 Buildings then injected water into the reactor cores at a rate of almost 30,000 gallons per minute. Following its single pass through the reactor core, process water was then discharged to the 107 Retention Basins where it cooled from 2-4 hours while short-lived radionuclides picked up in the core decayed. From the retention basins, the water re-entered the Columbia River via outfall structures and underground pipelines emerging at mid-channel (see Chapter 2, Section 3 for an extended discussion of water movement and Section 6 for reactor discharges).

Given the importance of water in cooling the reactor, and the consequences inherent in failing to maintain the reactor operating temperature within prescribed limits, Du Pont designed three independent systems to ensure uninterrupted water flow within the reactor. The primary pumping system operated on electricity. Nearly 75 percent of the electrical demand within the 100 Areas went to pumping and processing water. The secondary system relied on steam-driven turbines housed within the 184 Powerhouses. The tertiary system employed gravity feed from two 300,000-gallon elevated water tanks, the 187 structures. The sole purpose of the backup systems was to provide cooling water to the reactor while it was being shut down under emergency conditions, such as an electrical outage.

The second key element in reactor operations was the uranium fuel. Processed fuel elements were transported from the 300 Area to the 100 Areas where they were stored in the 103 Fresh Metal Buildings (103-B, 103-D, 103-F) before being loaded into the reactors. In reality, except for the initial fuel loading of a process tube, loading (charging) and unloading (discharging) were simultaneous processes. On a conceptual level, raw fuel loaded into the front face of the reactor would push processed fuel out the rear face, a simple concept that was difficult to execute. See the B Reactor HAER in Appendix B on the Internet for an extended discussion of the loading and unloading process.

Because of its configuration, irradiation of fuel elements within the reactor did not take place at a uniform rate. Fuel elements near the center of the reactor had a higher neutron flux than those around the edges. Physicists calculated the point at which irradiation had produced the optimum amount of plutonium-239 based on the position of the fuel elements within the reactor. Under-irradiation decreased the plutonium yield per unit of uranium, while over- irradiation increased the amount of undesirable isotopes such as plutonium-240 and plutonium-241. Tracking the progress of the fuel elements within each of the 2004 process tubes, these scientists called for an outage when approximately 25 percent of the tubes were ready for discharge.

Once discharged, the fuel elements were cooled in the fuel storage basin. Workers then prepared the fuel elements for rail shipment to the 200 North Area. Using a monorail, workers brought the buckets containing irradiated fuel elements to the adjacent transfer bay where they remotely placed the buckets within specifically designed lead casks and sealed the casks for shipment. Using an overhead crane, they pulled the filled casks from the deep-water basin and placed them within water-filled tanks on a flatbed rail car. Throughout the war years, fuel elements remained within the fuel storage basin for a very short period, usually days, before they were packaged for shipment to the 212 Lag Storage Buildings. Further radiological cooling occurred within a deep, water-filled basin in these buildings (Gerber et al. 1997, p. 5.81; see also the B Reactor HAER in Appendix B on the Internet).

Staff operated the reactor from the Control Room. Startup began when the reactor operator began the gradual and sequenced withdrawal of the nine horizontal control rods. The operator used seven of these control rods to advance, retard, or maintain the neutron flux throughout the reactor as required. The remaining two rods were used to fine-tune the reaction.

Under normal operating conditions, the reactor was shut down by fully inserting the horizontal control rods. When required, the reactor could be shut down quickly by inserting 29 vertical safety rods normally suspended above the reactor. Under emergency conditions, the "electromagnetic clutch holding each rod in the out position would be de-energized (de-magnetized), and the rods would free-fall by gravity into channels penetrating the reactor" (Gerber et al. 1997, p. 5.31). A second fail-safe system consisted of a liquid boron solution contained in tanks on top of the reactor that could be fed into the reactor through the vertical safety rod openings. As with other safety configurations, electrical systems were backed by hydraulic systems, which were backed by gravity. Chapter 2, Section 3 and the B Reactor HAER in Appendix B on the Internet describe in detail the reactor operations.

Chemical Separations

Although Du Pont constructed three fully independent chemical separations facilities on the Hanford Site, only the T and B complexes were used throughout World War II. This decision derived from the integrated nature of the Manhattan Project: "Originally eight separation plants were considered necessary, then six, then four. Finally, with the benefit of the operating experience and information obtained from the Clinton semi-works, we decided to build only three, of which two would operate and one [221-U] would serve as a reserve" (Groves 1983, p. 85).

Dissolving irradiated fuel elements, and isolating and concentrating the plutonium they contained was the third step in the production cycle. Leaving as they had arrived on rail cask cars, irradiated fuel elements were transported from the Lag Storage Buildings directly to Cell 3 of the process plants—a unique section of the building "designed to provide a 23-foot cell with adequate shielding to house the railroad tunnel into the building" (Gerber 1994a, p. 7). The chemical separations process began when the bridge crane operator removed the irradiated fuel elements from the casks and placed them into a dissolver tank. The tank was full or "charged" when a load of 1.5 metric tons of fuel elements had been transferred. Through remote manipulation, operators then chemically dissolved the aluminum cans encasing the irradiated fuel and transformed the solid fuel to a liquid solution. Operators, stationed at control panels in the shielded operating gallery, remotely processed this solution through a series of chemical and physical procedures from one cell to the next down the canyon until the 1.5 metric ton batch of irradiated fuel was reduced to 330 gallons of plutonium-bearing solution. The bismuth phosphate process separated plutonium from uranium and other irradiation-induced isotopes "by varying the valent state of the plutonium-239 and then repeatedly dissolving and centrifuging plutonium-bearing solutions" (Gerber 1994a, p. 4). Liquid waste from all process cycles was jetted to the single-shell, high level waste tanks constructed in the 200 Areas.

At this point, processing moved from the 221 Plants to the 224 Bulk Reduction Buildings (224-T, 224-B) where additional dissolving and centrifuging continued to concentrate the plutonium in solution, first using bismuth phosphate as a carrier then lanthanum fluoride. In the final step, the "solid plutonium lanthanum oxide was…dissolved with nitric acid, making plutonium nitrate" (Gerber 1994a, p. 11). The 330-gallon batch of plutonium-bearing solution piped into the 224 Building exited as 8 gallons of concentrated plutonium nitrate. Carefully placed within specially designed cans, teamsters transported the plutonium nitrate to the 231-Z Isolation Building in the 200-West Area. The designation "Z" was applied because the final step in the production cycle (purification) occurred in this building: "…a final product precipitation using sulfates and peroxide took place. The precipitate cake was dissolved with nitric acid, placed in small (10-inch-high) shipping cans, and boiled right in the cans using hot air. It was reduced to a wet nitrate paste (the HEW product)" (Gerber 1994a, p. 11).

These shipping cans, each holding approximately 1 kilogram of plutonium, were then transported to the 213 Structure in the 200-North Area. Excavated into the southeast face of Gable Mountain, this facility contained two magazine rooms (213-J, 213-K Vaults) "lined with concrete shelving interspersed with concrete brick partitions" (Gerber et al. 1997,

p. 5.82). Plutonium was stored in these vaults until it was shipped to Los Alamos. Sections 4 and 5 of Chapter 2 describe the chemical separations and plutonium finishing processes in detail.

Administrative, Facility, and Operations Support

Adhering to the siting requirements Groves established, the production cycle was segmented into discrete steps assigned to specific geographic areas of the Hanford Site, and, with the singular exceptions of fuel manufacturing and plutonium purification, duplicated at independent facilities within those areas. In reality then, the Hanford Site industrial complex consisted of seven production centers, each of which required administrative, facility, and operations support. For additional information on the construction, appearance, function, or history of many of these support facilities, see the Expanded Historic Property Inventory Forms (ExHPIF) or standard HPIF in Appendix B on the Internet.

Within the 100 Areas (100-B, 100-D, 100-F), a diverse workforce provided security, first aid, training, and maintenance services within specific ancillary buildings. For example, before and after each shift, all workers had to pass through the 1701 Guard House. Guards stationed at the entrances verified the identification of each employee and visitor before allowing access to any of the 100 Areas. Those who worked in the exclusion area containing the reactor complex then had to pass an additional identification check in the 1702 Badge House before proceeding to their assigned work area. A Patrol Headquarters (1720 Building), First Aid Station (1719 Building), and Fire Station (1709 Building) also were established within each 100 Area. Du Pont stressed fire awareness and the need for quick fire suppression as early as June 1943 because of the remoteness of the facilities, the vegetation surrounding them, and the number of wooden buildings contained within each Area (Gerber 2000, p. 3).

Working within the 1717 Combined Shop or 1722 Area Shop, craftsmen fabricated or repaired the equipment and materials needed to maintain ongoing operations. For instance, the 1717 Building contained "a machine shop, a carpenter shop, a pipe shop, and a sheet metal shop, an electric shop, a forge shop, a tool room, and six offices" (Gerber et al. 1997, p. 5.54). Vehicles were repaired and serviced within the 1716 Automotive Repair Shop. Craft supplies could be obtained from the 1713 Warehouse or 1715 Storage Building. Workers needing to change into coveralls and other personal protection equipment before working with radioactive materials would go to the 1707 Change House, where they might also shower or have lunch. Administrative staff oversaw operations, processed paper, maintained payrolls, ordered materials, and performed numerous other tasks within the 1704 Supervisor's Office.

Within the 200 Areas (200 East and 200 West), staff provided the same administrative, security, health, maintenance, and utility functions in facilities whose only distinction from those in the 100 Areas was often the number displayed above the entryway. As illustration, the 182 Pump Houses in the 100 Areas were labeled 282 in the 200 Areas, the 184 Power Houses and 1802 Overhead Steam Lines were identified as 284 and 2802, in the 200 Areas, and the 1707 Change Houses in the 100 Areas became 2707 in the 200 Areas. Like the 100 Areas, the 200 Areas also contained their own "coal-fired central power station to provide steam for heating and process equipment needs, a water supply, sanitary system, [and] road and railroad grid" (Gerber et al. 1997, p. 5.18).

The 200 Areas also contained support facilities specific to their function as chemical separations areas. The chemicals necessary to accomplish separations were delivered and stored in the 211 Tank Farms. Fresh chemicals could be supplied directly to the 221 Plant process cells from any of the 20 above-ground storage tanks or to the 271 Chemical Preparation and Service Buildings where they were mixed before being piped to the 221 Plants or 224 Buildings. Scientists in the 222 Sample Preparation Laboratories tested process solution samples withdrawn throughout the separation process. "Since the entire separation process was conducted remotely, the only way to verify that the process was working within specifications was to draw and test samples" (Gerber et al. 1997, p. 5.38). Finally, in this sequencing from start to finish, the 292 Exhaust Gas Laboratories supplied information on the level of chemical and radioactive contaminants exiting the process exhaust stack.

The 300 Area also contained a complete set of administrative, health, safety, and maintenance support facilities. However, operations support facilities within the 300 Area were directed not only toward fuel manufacturing (the area's

primary mission) but also toward chemical separations process improvement and essential materials testing (Gerber et al. 1997). An example is the role of the 305 Test Pile (reactor) in materials testing for the Hanford Site production reactors.

Another primary investigative focus within the 300 Area was research and development of the chemical separations process. As another example of the synergetic integration of the Manhattan Project, research conducted at the Clinton Semiworks resulted in changes in the design and mission of the 321 Separations Laboratory at the Hanford Site. Originally designed only for "cold" pilot-scale research using unirradiated sources, a "hot lab" was added just before completion of the 321 Building because scientists at the Clinton Semiworks had demonstrated the importance of understanding and controlling factors affecting chemical separations under actual operating conditions.

To meet accelerating production demands, research staff in the Hanford Site 3706 Radiochemistry Laboratory examined each operation phase to make the bismuth phosphate process faster and more efficient, thereby extracting the greatest amount of plutonium in the least amount of time. Research conducted in the 3706 Building was tested experimentally in the 321 Building "canyon," then applied within the 221 separations plants. Rhodes (1986, p. 604) recounts Glenn Seaborg's proud notation that "yields in the first plant runs…ranged between 60 and 70 per cent…[and] reached 90 per cent early in February 1945." While this research was under way, other scientists in the 3706 Building focused on "metallurgical examination of irradiated fuel elements from the reactors, fuel development for the 313 Building, examination of graphite from the experimental levels of the 100 Area piles [reactors], special sample analyses from the spectroscopy and radiocounting activities, and multifaceted analyses for environmental and personal survey programs" (Gerber et al. 1997, p. 5.39). See Chapter 2, Section 7 for extensive coverage of research and development activities at the Hanford Site.

DISCHARGE AND WASTE: THE RESIDUAL OF PRODUCTION

Leona Marshall, the only woman physicist on Fermi's staff, had occasion to visit the Hanford Site. Some years later, she offered this first-hand remembrance: "When the Queen Marys began to function, dissolving the irradiated slugs [fuel elements] in concentrated nitric acid, great plumes of brown fumes blossomed above the concrete canyons, climbed thousands of feet into the air, and drifted sideways as they cooled, blown by the winds aloft" (Marshall quoted in Rhodes 1986, p. 604).

As disquieting as this mental image may be, we are reminded that hindsight is a stern judge. While the discharge and disposal methods used throughout World War II, indeed through 1970, were primitive by today's standards, "the nuclear weapons industry typically used waste-disposal methods that were considered acceptable at the time" (DOE 1995e, p. 23). At the time, the "imperatives of the nuclear arms race…demanded that weapons production and testing, rather than waste management and the control of environmental contamination, be given the first priority" (DOE 1995e, p. 5). Along these same lines, Findlay and Hevly (1995, p. 50), referring specifically to the Hanford Site, provide a summary less encumbered by government perspective: "Wartime exigencies dictated haste at the expense of safety and environmental concerns. Du Pont and the Army "took risks to get results" because they were in a hurry. They also cut corners with the expectation that such emergency conditions would last only a short while and that more effective safeguards would be introduced once the war ended."

Groves' recollection in the early 1960s confirms Findlay and Hevly's later analysis: "We had always thought that it would be possible to eliminate much of the radioactive problem in the future. We also hoped to recover the uranium remaining in the existing solutions and to reduce the bulk of the radioactive waste materials, thus making them easier to handle" (Groves 1983, p. 91). An abiding concern with the long-term effects of radioactive waste on future generations was also apparent at the time. In an interview given in 1948, Dr. Lyle Borst, then director of the Brookhaven National Laboratory Pile Project and the former supervisor of research at the X-10 Graphite Reactor, observed:

> *"For the first time man is creating something that cannot be destroyed – radioactive materials…If their radiation gets into biological organisms, including human beings, it will destroy them…[present disposal methods, that is, thick concrete tanks, sunk deep into the ground, are adequate]. But since we're thinking in terms of geological*

ages, how are we going to guarantee that some damn-fool archeologist won't go sticking his nose into the stuff ten thousand years from now?" - Lang 1948, p. 203

Plutonium production generated large volumes of radioactive and chemical waste. Hanford workers had to contend with these wastes in three forms: solid, liquid, and gas. The overview in this chapter discusses only methods developed and used during the Manhattan Project for handling and managing radioactive or toxic wastes. Chapter 2, Section 6 and the pertinent ExHPIFs and HPIFs offer more detail on how waste has been managed throughout the Manhattan Project and the Cold War Era.

Solid Waste

Burial of radioactively contaminated solid waste within shallow excavations was the preferred method of disposal ever since this type of waste began to accumulate at the Hanford Site. Low-level solid waste contained small amounts of radioactivity dispersed in large amounts of materials. Examples included protective clothing, tools, equipment, machinery, debris, sludge and other items contaminated with radionuclides. Within the 100 Areas, low-level solid waste burial grounds consisted of simple pit or trench excavations with no lining materials. Generally, one large burial ground was established at each reactor complex to facilitate burial of materials generated within that complex. Smaller pits or trenches were excavated as needed or to accommodate specific items. Low-level solid waste in the 200 Areas, namely protective clothing, obsolete or failed equipment, and other types of materials similar to those generated in the 100 Areas were disposed of in unlined burial grounds near the process facilities. Mixing of wastes (such as hazardous and radioactive, combustible, and non combustible) within the same burial ground was a defining characteristic of early waste disposal methods within both areas.

In addition to low-level solid waste such as protective clothing and process equipment, generated in common with the other areas, workers in the 300 Area also had to dispose of wastes resulting from the manufacture of fuel elements and research and development activities. Uranium scraps, primarily lathe turnings, billet ends, and container residue, were stored in 5-gallon cans in and around the 303 Buildings. Metal oxide from fuel elements that had failed the autoclave test was stored in 30-gallon drums as was uranium sludge (Gerber 1992c, p. 6). Two solid waste burial grounds were constructed within the 300 Area during the Manhattan Project. The first (Burial Ground 618-8) was used from 1943-1944, the second (Burial Ground 618-1) from 1945 to 1951 (Gerber 1993b, p. 59).

Liquid Waste

Within the 100 Areas, low-level liquid waste, primarily reactor process water, was discharged to retention basins and ultimately to the Columbia River. Fuel storage basin overflows, maintenance and decontamination activities, and other activities also generated low-level radioactive liquid wastes. Many of these wastes were often discharged to open pits or cribs (an underground chamber constructed of loosely spaced timbers) adjacent to the reactor buildings. Contaminated water from individual process tubes in which a fuel cladding failure had occurred was generally discharged to a more distant crib where it percolated into the soil. No high-level liquid wastes were generated in the 100 Areas.

It is important to note for the 200 Area that high-level radioactive liquid wastes, generated at a rate of 10,000 gallons per ton of irradiated fuel processed, were always sent directly to underground storage tanks during World War II. Such was not the case, however, with low-level liquid waste. Herbert M. Parker, chief health physicist for the Hanford Site during the Manhattan Project, characterized the earliest low-level liquid waste disposal methods within the 200 Areas as temporary and expedient, devised "to avoid absurd costs on tank storage, [or] evaporation equipment" (Gerber 1992b, p. 45). His reference was to direct discharge of low-level wastes within natural depressions. This practice was abandoned early in 1945 because these resulting swamps produced higher than acceptable radiation levels. Throughout the remainder of the war, indeed until their general abandonment in mid-1947, most low-level liquid wastes were discharged to reverse wells (perforated casings extending to near groundwater depth). Some process wastes, however, were handled differently. For example, piped first to a settling tank where suspended particulates dropped out, process waste from the 224 Building was then mixed with discharged process cooling water from the 221 Plant before being

piped to one of two 500,000-gallon retention basins. These basins "overflowed into open earthen drainage ditches that ran far out into the desert" (Gerber 1994a, p. 23).

Low-level liquid wastes from the 300 Area laboratories and fabrication facilities were collected in a centralized process sewer system (3904 Structure) and discharged to a process pond adjacent to the Columbia River. The process sewer system was distinct from and not connected to the sanitary sewer system (3903 Structure). All high-level liquid wastes from the 3706 Building were sent to the process sewer system, while high-level liquid waste from the 321 Building was discharged to four underground tanks, a reverse well, or the process sewer (Gerber 1992c).

Gaseous Waste

In designing the Hanford Site reactors, Du Pont realized, as had Fermi, that reactivity would increase if air were removed from the area within which the reaction occurred. This efficiency would occur because nitrogen gas, the largest component of air, attracts neutrons and therefore acts as a poison. Another inducement to remove air from the reactor arose from the fact that argon gas, a very minor component of air, quickly became radioactive under neutron bombardment. Escaping from the reaction area, this gas would be hazardous.

To address these issues, the design engineers made the reactor air-tight and installed a "circulating helium atmosphere" that "displaced neutron-absorbing air from the reactor core, and removed gases generated by the reactor" (DOE 1997e, p. 164). The 115 Gas Purification Building, adjacent to the reactor building, contained all the equipment necessary to purify and circulate the helium, which was stored in high-pressure storage tanks in the 110 Process Gas Storage Building. An integrated ventilation and exhaust system was installed throughout the reactor building that channeled air from areas of no contamination to areas of high contamination where they were collected and released. Engineers designed this negative pressure gradient for every building where radiation would be present throughout the Hanford Site. For the 100 Area reactors, two supply fans "washed, filtered, and tempered" outside air coming into the building, while two exhaust fans discharged circulated air through an underground concrete duct to the base of the 116 Exhaust Stack. Released without filtration, low-level process gases passed to the atmosphere from the top of the stack at 200 feet (Wahlen 1989, p. 28).

From the beginning, the Metallurgical Laboratory scientists knew that chemical separation would generate highly toxic fumes in the metal dissolving phase. Early operations within the Clinton Semiworks demonstrated that gases generated throughout the separations process contained radioactive fission products. To address these off-gases at the Hanford Site, Du Pont engineered a ventilation and exhaust system in the canyon buildings with the 291 Exhaust Building and Stack as the point of release. Measuring 200 feet high, the stack "functioned to exhaust process gases…and to provide additional 'diluting air' deemed essential to the safe dispersion of process gases to the atmosphere" (Gerber 1994a, p. 16). To assist with their unfiltered dispersion into the atmosphere, Du Pont engineers increased the normal flow of air and gases from 40,000-60,000 cubic feet per minute using three large fans within the stack.

In the 321 Building, nitrous oxide and fission gases from research to improve the chemical separations process were released directly to the atmosphere through an exhaust stack on the building's roof. Laboratory exhausts generated within the 3706 Building simply discharged through ventilation dormers on the roof (Gerber 1992c).

WORKER AND ENVIRONMENTAL MONITORING

In reviewing the formative stages of personal and environmental monitoring programs, Gerber (1992b, p. 11) observed that "the new sciences of health physics and environmental monitoring developed rapidly at the [Hanford] Site, pioneering advances in instrumentation procedures, working conditions, and methods of analytical chemistry to process substances never before sampled." After developing a pilot health physics program at the Clinton Engineer Works X-10 complex, Herbert Parker, a radiological physicist, left Tennessee to return to Washington State. Together with Carl C. Gamertsfelder (an x-ray diffraction scientist), William D. Norwood (a physician), and a team of fifteen others, Parker established the Health Instruments Section for the Hanford Site in July 1944.

The Health Instruments Section "was charged with defining and measuring radiological hazards, establishing procedures to make jobs in plutonium production safe for workers, and developing and calibrating instruments." These tasks were made very challenging "because strict MED security regulations precluded revealing to most employees even the existence of radioactivity" (Gerber 1992b, p. 12). While operating in an information vacuum, workers found that the regulations drafted by the Health Instruments Section were meticulously enforced. For example, each employee wore a film badge and two "pencils" (a small, tubular radiation monitor) throughout their shift. They were required to have the pencils read daily, while the film badges were submitted for reading weekly. Those who worked in proximity to radiation sources wore additional personal monitors and provided samples for urinalysis regularly. All this as protection against a danger about which they could not even be informed. Indeed, discussion of radiation monitoring was so sensitive that even the term could not be used. It was referred to by its code named "health physics."

Groves' selection of the Hanford Site was itself an acknowledgement of the dangers inherent in working with radiation. Even amidst the intense pressures of construction, Groves understood the need to determine where and how contamination might spread, and what effects it might have: "An accident might release radioactivity into the air; that called for thorough meteorological work. The river water needed study; so did the river's valuable salmon, to see how they would take to mild doses of transient radioactivity from pile [reactor] discharge flow" (Rhodes 1986, p. 497).

Beginning in June 1943, a meteorological team began to document "dominant wind patterns, velocities, and variances" at the Hanford Site. Once a baseline had been established, general meteorological studies gave way to "wind dispersion tests with oil fog (SO_2 [sulfur dioxide]), beginning in the partially completed T Plant Stack (291-T) as early as April 1944." By Fall 1944, the C Plant Stack and then the Meteorological Tower (622 Structure), a 400-foot-high metal lattice work erected outside of the 200 West Area, were used in sequence to determine off-gas trajectories because pre-operation activities precluded the use of the 291-T Stack. "So extensive was the weather study and forecasting effort that by the end of 1944, over 36,000 individual readings on wind dilution patterns had been recorded in the 200 West Area" (Gerber 1994a, p. 29). Du Pont would use the information gained in these studies to determine the optimum conditions for atmospheric dispersal of process wastes, particularly the off-gases produced in chemical separations.

Twenty-nine Air Monitoring Stations (614 Buildings) were constructed to track the waste stream and evaluate the dispersion model. These small, wooden structures housed continuous air samplers that technicians periodically analyzed for the presence of plutonium nitrate dust as well as iodine-131 and other fission isotopes. Twelve of these sampling stations were placed in the 200 Areas, fifteen were distributed across the Hanford Site (including Richland Village), and two were located off site. Acting on the data obtained from these stations, Du Pont determined by June 1945 that initial dissolving operations should be limited to the night shift since dispersal characteristics were generally more favorable. Also concurrent with the commencement of chemical separations activities, the Health Instruments Section began regional investigations of the deposition of airborne fission materials, particularly iodine-131, and their accumulation and effect within both animals and vegetation (Gerber 1994a, Gerber et al. 1997).

Before operations started, in fact beginning with design changes to the reactor intake pipes, the Corps considered the effects of plutonium production on the Columbia River and its aquatic resources, particularly salmon. For example, the Corps, on Groves' suggestion, established the Applied Fisheries Laboratory at the University of Washington in 1943 under the direction of Lauren Donaldson (Gerber 1992b). Studies on the effects of radiation on fish were initially conducted on the Seattle campus to maintain what would now be called "plausible deniability" between the research being conducted there and the production of plutonium at the Hanford Site. Exposing fish to x-rays, the radiation source available for research, provided useful but limited data. If questions regarding the effects of reactor effluent on fish were to be answered, then direct exposure to reactor effluent, and the isotopes it contained, had to occur.

Consequently in June 1945, Richard Foster began to conduct onsite research within the 100-F Area. Effluent water of differing strengths and temperatures was discharged to troughs and ponds holding salmon and trout to determine tolerances, diseases, and reproductive viability. Initial results indicated that "[y]oung fish, possibly due to higher metabolic rates, accumulated proportionately more radioactivity in their tissues than did adults. Accumulation of

radioactivity occurred more slowly in cooler water, and activity levels differed among various fish tissues" (Gerber 1992b, p. 36). Disclosure of either the conduct of these first-of-a-kind studies or their results was not allowed until after World War II. Dr. Ronald Katherine, a leading expert in radiological health physics, maintains that these two studies mark the beginning of the longest continuously operating environmental monitoring program in the United States. Chapter 2, Section 7 discusses the atmospheric, radiobiological, and radioecological research conducted at the Hanford Site.

SECRECY AND SECURITY

Secrecy enveloped atomic research from the onset of the War in Europe until the flash at Hiroshima made clear to the world that one nation had realized the vision patented by Leo Szilard in 1934. Security measures, many of which violated individual civil liberties, were constants throughout the Manhattan Project. As Findlay and Hevly (1995, p. 39) observed, the Richland Village may have escaped the fence that enclosed both Los Alamos and the Clinton Engineer Works, but the "Army would still police Richland and watch its residents carefully – wartime censors examined each departing letter; security personnel listened in on phone calls; [and] hotel porters acted as 'counter-espionage agents'." In fact, undercover agents were everywhere, assuming roles that provided them with access to the operating facilities, laboratories, and craft shops. Many recruited informants to extend their reach.

Security concerns associated with atomic weapons development, however, were not confined to the Hanford Site and continued after the end of World War II. Discussing line work at the Rocky Flats Plant, an Atomic Energy Commission installation devoted to the manufacture of plutonium pits and other weapon components established in 1951, Jack Weaver recalled: "Nobody talked about what we were doing in those days. We didn't even talk about it amongst ourselves, let alone with our families and friends offsite. On the floor even, we referred to "Y" or "Z" or "U" and not to beryllium or plutonium or enriched uranium" (DOE 1995e, p. 17).

These remarks mirror those described elsewhere by retired Hanford Site employees and demonstrate that Groves' philosophy of "compartmentalization" permeated the national atomic weapons program. As Groves recounted: "We made certain that each member of the project thoroughly understood his part in the total effort – that, and nothing more" (Groves 1983, p. xv).

The Hanford Site Patrol, established under the Plant Protection Program developed by Du Pont and approved by Colonel Matthias in March 1943, provided front-line security for the Hanford Site. The Hanford Site Patrol partnered with and sought assistance from the Corps and the Federal Bureau of Investigation, both of whom established a local presence in conducting background checks, safeguarding information, and preventing theft of materials among other tasks. No new employee was hired without a background investigation commensurate with the position they would fill. Having accepted a position, each employee signed a "Declaration of Secrecy," enforceable under the National Espionage Act or the Federal Sabotage Act with imprisonment or heavy fines if breached. The Corps established classified areas and materials, and the Hanford Site Patrol provided security orientation and education so employees did not transgress boundaries with respect to either facilities or documents to which they did not have authorized access. Employees seeking information not essential to their specific tasks or speculating in rumors detrimental to the workforce were promptly disciplined with reprimand or termination. Some found these measures oppressive or excessive and, as a final irony, were required to resign a Declaration of Secrecy before they could terminate their employment. In fact, all employees renewed this pledge of allegiance before terminating employment under any circumstances.

The Hanford Site Patrol conducted foot, vehicle, and boat patrol of the Hanford Site perimeter as well as the entry points to all operational areas from 1943 until August 1944. At that time, the Corps assumed responsibility for perimeter patrol and also established an Air Patrol to enforce the restricted air space established over the Hanford Site. The Hanford Site Patrol then concentrated on patrolling the operational areas and the facilities within and between them. Ensuring the security of classified information remained one of their primary tasks. The Hanford Site Patrol made daily inspections to verify that filing cabinets containing classified data remained locked. An unlocked cabinet was investigated to determine that its contents were intact. Armed Hanford Site Patrol staff also accompanied every shipment of uranium metal, fuel

elements, irradiated fuel, and concentrated plutonium nitrate throughout the production cycle. Chapter 2, Section 8 describes in detail the secrecy and security measures in place at the Hanford Site.

ALAMOGORDO BOMBING RANGE, HIROSHIMA, AND NAGASAKI

By late 1944, the Hanford Site was fully operational, dependably delivering plutonium to Los Alamos for research, testing, and assembly. Though still tightly under wrap, the contribution the Hanford Site workforce made to the Manhattan Project would soon become apparent, pending resolution of one critical problem (see sidebar box).

> ***"Field tests performed with uranium-235 prototypes in late 1944 eased doubts about the artillery method to be employed in the uranium bomb. It was clear that the uranium-235 from Oak Ridge would be used in a gun-type nuclear device to meet the August 1 [1945] deadline Groves had given General Marshall and the Joint Chiefs of Staff. The plutonium produced at such expense and effort at Hanford would not fit into wartime planning unless a breakthrough in implosion technology occurred."*** **- Gosling 1999, p. 42**

The hard-fought breakthrough came in April 1945 when the combined efforts of inveterate chemists and metallurgists at Los Alamos led to precise techniques for producing plutonium metal. This occurred just 3 months ahead of the July 4 test firing Oppenheimer had scheduled for the plutonium bomb he christened "Trinity" (Gosling 1999). When Groves asked many years later why he had chosen that name, Oppenheimer responded that the reason was not clear even to him, but noted that certain thoughts had been in his mind. In particular, he mentioned a devotional poem by John Donne, which opened with the line: "Batter my heart, three person'd God…" "Beyond this," he said, "I have no clue" (Oppenheimer, quoted in Rhodes 1986, pp. 571-572).

Gosling (1999, p. 48) writes that "At precisely 5:30 a.m., on Monday, July 16, 1945 the atomic age began" at an isolated location within the Alamogordo Bombing Range (which later became the White Sands Missile Range) also known by the Spanish name Jornada del Muerto – the Journey of Death. With an explosive force of approximately 18.6 kilotons of power, the Trinity "device" turned darkness into light and the cool, damp desert air into searing heat. Isidor Rabi recounts the moment of detonation:

> *"Suddenly, there was an enormous flash of light, the brightest light I have ever seen or that I think anyone has ever seen. It blasted; it pounced; it bored its way right through you. It was a vision which was seen with more than the eye. It was seen to last forever. You would wish it would stop; altogether it lasted about two seconds. Finally it was over, diminishing, and we looked toward the place where the bomb had been; there was an enormous ball of fire which grew and grew and rolled as it grew; it went up into the air, in yellow flashes and into scarlet and green. It looked menacing. It seemed to come toward one."* - Rabi, quoted in Rhodes 1986, p. 672

No longer was there any doubt that the implosion bomb, fueled by plutonium irradiated at the Hanford Site's B Reactor and separated at T Plant, would work.

President Roosevelt did not live to see the atomic age. He died of a cerebral hemorrhage on April 12, 1945 in Warm Springs, Georgia. Harry S. Truman assumed the Presidency that evening and with it the need to determine national policy in the waning days of World War II. Before he was fully advised of the Manhattan Project, a bombing raid on Tokyo on April 13 destroyed the building containing Japan's gaseous thermal diffusion experiment. "It burned to the ground and took the Japanese atomic bomb project with it" (Rhodes 1986, p. 612). About the same time, American forces had confiscated the Belgian uranium ore stored in Strassfurt, Germany, crippling the German atomic weapons program and thereby eliminating any potential atomic threat from the Axis powers.

Despite Germany's surrender, Japan continued to resist the unconditional surrender demanded by the Allied Forces. The success of the Trinity test and word that both the enriched uranium and plutonium bombs would be ready for use by early August enabled President Truman to avoid extending an offer of surrender to Japan that allowed the Imperial

On May 7, 1945, Germany surrendered unconditionally.

Emperor to continue to rule. Nuclear weapons might force a surrender and negate the need to invade Japan, which, based on bitter experience gained from military encounters on the Pacific islands, would have resulted in significant loss of lives on both sides. Without an invasion, Russian entry into the Pacific theater would not be necessary, which was equally important given Russia's "designs on Eastern Europe and Germany." Russia could not "expect to share in the postwar administration of Japan" (Gosling 1999, pp. 50-51).

On July 26, 1945, the Potsdam Declaration was issued via radio to Japan. In it, the President of the United States, the President of Nationalist China, and the Prime Minister of Great Britain called on the Japanese government to "proclaim now the unconditional surrender of all Japanese armed forces…The alternative for Japan is prompt and utter destruction" (Rhodes 1986, p. 692). Rejection came quickly on July 29.

At 2:45 a.m. on the morning of August 6, 1945, the *Enola Gay*, code named Dimples Eight Two, began its take-off run down the Tinian airfield with "Little Boy," the enriched uranium gun-style bomb, securely shackled within the bomb bay. Little Boy was the brother of "Fat Man"—the other bomb planned for Japan. Confident that the gun design would work with an enriched uranium core, Oppenheimer never tested a prototype of this bomb as he had done with the Trinity plutonium device. This mission was both test and application: "Little Boy exploded at 8:16:02 Hiroshima time, 43 seconds after it left the Enola Gay, 1,900 feet above the courtyard of Shima Hospital, 550 feet southeast of Thomas Ferebee's aiming point, Aioi Bridge," (Rhodes 1986, p. 711) with a yield equivalent to 15,000 tons of TNT (DOE 2000a).

"Little Boy killed 70,000 people (including about twenty American airmen being held as POWs) and injured another 70,000. By the end of 1945, the Hiroshima death toll rose to 140,000 as radiation sickness deaths mounted. Five years later the total reached 200,000. The bomb caused total devastation for five square miles, with almost all of the buildings in the city either destroyed or damaged." - **Gosling 1999, p. 51**

Radio stations all over the United States broadcast the news of Hiroshima within hours of its bombing. Reading from a press release issued by President Truman, announcers informed the public for the first time of the existence of the atomic bomb and of President Truman's resolve to drop additional atomic bombs if Japan did not offer its unconditional surrender. Rhodes (1986, p. 736) opines that the civilian Japanese population viewed the atomic bomb "like a golden opportunity to surrender without shame, but the admirals and generals still despised unconditional surrender and refused to concur." Foreign Minister Togo again reached out to Russia to mediate an agreement. Instead, Ambassador Naotake Sato was informed on August 8 that Russia would declare war on Japan at midnight, August 9 (Rhodes 1986).

"Fat Man exploded 1,650 feet above the slopes of the city with a force of 21,000 tons of TNT. Fat Man killed 40,000 people and injured 60,000 more. Three square miles of the city were destroyed, less than Hiroshima because of the steep hills surrounding Nagasaki. By January 1946, 70,000 people had died in Nagasaki. The total eventually reached 140,000, with a death rate similar to that of Hiroshima." - **Gosling 1999, pp. 53-54**

The Fat Man bomb (named in honor of Winston Churchill and fueled by Hanford Site plutonium) was originally scheduled to be dropped August 11, 1945, but the drop date was advanced by 2 days to take advantage of forecasted good weather. At 3:47 a.m. on August 9, *Bock's Car* lifted off from Tinian under the command of Major Charles W. Sweeny rather than the B-29's namesake Frederick Bock. Kokura Arsenal on Kyushu Island was the primary target. The Mitsubishi plant at Nagasaki, where the torpedoes used at Pearl Harbor originated, was the secondary target. Bad weather conditions caused Sweeny to abort the drop over Kokura, despite making three passes over the target area. Running low on fuel because the reserve tank was not operational, Sweeny turned toward Nagasaki where he could make one pass before heading for an emergency landing at Okinawa. A "twenty-second visual run" through an otherwise clouded sky

provided the only opportunity to locate the aiming point. The bombardier only had time to fix on a stadium several miles upriver (Rhodes 1986).

Even after the Nagasaki bombing, "civilian and military leaders continued to struggle in deadlocked debate" (Rhodes 1986, p. 743). Taking the initiative, Emperor Hirohito "forced the issue" and delivered an offer of conditional surrender to Washington through Switzerland on August 10. The condition was that he remain as sovereign. Taking advice from Stimson, Byrnes, and Secretary of the Navy James Forrestal, President Truman authorized Byrnes to draft a response that stated that the Emperor's rule would be "subject to the Supreme Commander of the Allied Powers." The reply was both broadcast on August 11 and routed for return through Switzerland.

News of Japan's surrender was celebrated across the United States, but no more so than in the "atomic city" of Richland, whose "victory celebrations were covered in newspapers and on radio programs throughout the nation, and the little city basked in admiration and praise." Groves came to the Hanford Site in October and presented each employee, for their part in the war effort, the Army-Navy "E" Award, "the highest civilian production commendation," and an "A-bomb" pin authorized by the War Department (Gerber 1992b, p. 17).

END OF THE MANHATTAN PROJECT: 1946

The Manhattan Project did not end with the announcement of the Hiroshima bomb. A well-controlled breach in the wall of secrecy allowed the government to indulge public curiosity without revealing sensitive information. *Atomic Energy for Military Purposes*, authored by physicist Henry DeWolf Smyth and issued on August 12, 1946 made information on atomic bomb development available to the general public: "It appalled the British, enlightened the Soviets on which approaches to isotope separation not to pursue and – Groves' intention in releasing it – defined what might be public and what secret about the atomic bomb program, thereby forestalling information leaks" (Rhodes 1986, p. 750).

While the future of atomic weapons and atomic research would be debated somewhat more openly now, public disclosure did not stop the secret production and stockpiling of atomic weapons that continued, albeit at a reduced pace. In September 1945 under a plan approved by Stimson and Marshall, Groves either closed or idled operations at the Clinton Engineer Works. At the Hanford Site, Groves first reduced the operating power at all three reactors, then shut down B Reactor altogether in December 1946. During this slowdown only T Plant was used for chemical separations. Finally, Groves re-assigned weapon assembly responsibility from Los Alamos to the Sandia Base in Albuquerque (Gerber 1992b, Gosling 1999). Manhattan Project operations ratcheted down while the formulation of a national atomic policy moved to the forefront.

As early as spring 1944, Niels Bohr attempted to impress on both President Roosevelt and Prime Minister Churchill the need to freely exchange information on nuclear weapons development both to secure international agreement on control and avoid international proliferation – an arms race. Rhodes (1986, p. 528) summarizes the political implications of Bohr's message to these world leaders: "Tell the Soviet Union soon, before the first bombs were nearly built, that a bomb project was under way, and the confidence might lead to negotiations on postwar arms control. Let the Soviet Union discover the information on its own, build the bombs and drop them, oppose the Soviets at the end of the war with an Anglo-American nuclear monopoly, and the likeliest outcome was a nuclear arms race."

Bohr did not succeed with either man. Churchill chastised him, and while President Roosevelt was more cordial and agreeable, he agreed in the end with Churchill that secrecy would be maintained. Focusing on the immediate situation, both lost sight of Bohr's deeper message, that relationships among nations would be changed fundamentally after the bomb since no one could win a war between nations armed with atomic weapons.

Like Bohr, many of the scientists who developed the atomic bomb expressed misgivings about its use. Leo Szilard, the man who pushed hardest for the production of nuclear weapons in 1939, became one of the most ardent voices in seeking to control their use and spread. He made four attempts to influence policy during the spring and summer of

1945. In March, Szilard drafted a memorandum for President Roosevelt and requested a letter of introduction from Einstein to secure a meeting with the President. Roosevelt died before their meeting could be arranged. Undeterred, Szilard sought to meet with President Truman in May. President Truman instead directed him to James Byrnes in South Carolina. In response to Szilard's concern that "the greatest immediate danger which faces us is the probability that our 'demonstration' of the bomb will precipitate a race in the production of these devices between the United States and Russia," Byrnes responded first that the use of the bomb would satisfy Congress that the two billion dollars spent secretly in its development was justified, and that a demonstration of the power of the bomb might incline Russia to withdraw its troops from eastern Europe after the war (Szilard, quoted in Rhodes 1986, p. 637).

Discouraged but still undeterred, Szilard worked with James Franck, Glenn Seaborg, and other members of the Metallurgical Laboratory's Committee on the Social and Political Implications of the Atomic Bomb to assert their positions to the Interim Committee's Scientific Panel that only international control of atomic power would prevent an arms race and that the bomb should be demonstrated on an uninhabited area before being used against Japan. Theirs was the minority view, as the Scientific Panel met with the Interim Committee on May 31 and opted for maintaining nuclear monopoly and conducting an unannounced strike on Japan (Gosling 1999).

Finally, in July, Szilard drafted and circulated a petition to President Truman in which he urged him not to use the bomb: "The last few years show a marked tendency toward increasing ruthlessness. At present our Air Force, striking at the Japanese cities, are using the same methods of warfare which were condemned by American public opinion only a few years ago when applied by the Germans to the cities of England. Our use of atomic bombs in this war would carry the world a long way further on this path of ruthlessness" (Szilard 1945).

Lanouette (1999, p. 6) notes that 155 scientists from the Metallurgical Laboratory and the Clinton Engineer Works signed drafts of this petition that Oppenheimer banned at Los Alamos. Groves went further than Oppenheimer. Looking to dismiss the petition, he polled the scientists, but "when 72 percent of those responding favored a demonstration of the bomb, the Army bureaucracy suppressed both the petition and the poll."

Two events in late September 1945 framed the debate for international control of atomic weapons. Shortly after Japan's surrender, having seen and keenly felt the destructive power unleashed by the atomic bomb, Oppenheimer brought a letter drafted by the Interim Committee's Scientific Panel to Washington to deliver to Stimson. In the letter, the Panel outlined their concerns that further research would introduce far more powerful bombs, that no military counter measures existed then or would be found later to defend against atomic bombs, and that safety lay not in developing or stockpiling weapons but in "making future wars impossible" (Rhodes 1986, pp. 751-752). Clearly, the Panel's opinion had changed, moved both by the aftermath of the bombing and the earlier admonishments of Bohr and Szilard. Oppenheimer did not see Stimson, who was away when Oppenheimer arrived in Washington. Instead, Oppenheimer met with Vannevar Bush and Stimson's aide George L. Harrison. Neither was very receptive. When the letter reached Byrnes through Harrison, Byrnes instructed Oppenheimer to continue the work initiated under the Manhattan Project "full steam ahead" because of the deteriorating international situation (Rhodes 1986, p. 752).

The second event, the Conference on Atomic Energy Control, was a 2-day meeting organized by Szilard and University of Chicago chancellor Robert M. Hutchins. Following the revelation of the atomic bomb, Szilard felt the time was right to "get thoughtful and influential people to think about what the bomb might mean to the world, and how the world and America could adjust to its existence" (Szilard, quoted in Rhodes 1986, p. 750). Jacob Viner expounded on the concept of "psychological warfare" between equally armed nations wherein fear of the retaliatory effects of the bomb would deter its use. If the "war of nerves" maintained fear at a level appropriate for deterrence, the net effect would be peace. Szilard noted that deterrence might bring a "durable peace," but only "world government" could ensure a "permanent peace" (Rhodes 1986, p. 753).

Unfortunately for those proposing full disclosure and international control, initial congressional legislation, the May-Johnson bill, drew heavily from the draft legislation prepared by the Interim Committee prior to Hiroshima and Nagasaki bombings. Acting on President Truman's charge to formulate a nuclear weapons policy, the Interim Committee had

developed draft legislation in July that proposed a "peacetime organization with responsibilities very similar to those of the Manhattan Project." The government would continue to control nuclear research and development through a board of commissioners weighted in favor of the military. Security would be maintained through fines and imprisonment. President Truman initially pushed for passage of the May-Johnson bill on October 3, 1945. Opponents of the bill complained that its provision for continued military control "tolerable during war…was unacceptable during peacetime when free scientific interchange should be resumed." Debate on the bill stalled "through a parliamentary maneuver" (Gosling 1999, p. 57).

On December 20, 1945, Brien McMahon, chairman of the Senate Special Committee on Atomic Energy, introduced an alternative to the May-Johnson bill, which had steadily lost ground, first from scientific opposition, then from President Truman's withdrawal of support. The bill was debated for 5 months. Groves objected to the bill and cited its "weak security provisions, the low military presence, and…[the] provision that atomic weapons be held in civilian rather than military custody." Ultimately, civilian control prevailed. President Truman signed the bill, known as the Atomic Energy Act of 1946, on August 1 and thereby gave control of atomic research and development to the newly created United States Atomic Energy Commission effective January 1, 1947 (Gosling 1999, p. 57).

Two of Groves' last acts as commander of the Manhattan Project demonstrated his acknowledgement of increased civilian interaction and control. In June 1946, nine plutonium bombs constituted the entire U.S. nuclear weapons arsenal (Rhodes 1986). During July of that year, two were detonated under *Operation Crossroads*. With a "large, invited audience of journalists, scientists, military officers, congressmen, and foreign observers" in attendance, Shot Able and Shot Baker, each with an explosive yield of 21,000 tons of TNT, were detonated on Bikini Atoll on July 1 and 15 respectively. These public tests were the last conducted by the Manhattan Project (Gosling 1999, p. 55).

Late in 1946 in response to Oppenheimer's request for increased research and development funding, Groves established three national laboratories – Argonne, Brookhaven, and Oak Ridge (Gerber 1992b). The Argonne and Oak Ridge national laboratories grew out of their military background, and even their civilian focus remained tied to applied atomic research, that is, process improvement. The Brookhaven National Laboratory, on the other hand, was a "civilian institution from its conception, and its program was…oriented to basic research," that is, the discovery or understanding of previously unknown structures or characteristics principally in the fields of physics, engineering, biology, and medicine (Crease 1999, p. 1).

The Manhattan Project lasted 4 years from 1942-1946 and estimates on total expenditures range from $1.8 to $2.2 billion. Today, this would be equivalent to over $20 billion (Bracchini 1997). It succeeded in what it had set out to do – develop an atomic bomb for military use. Whether it had made the world more secure was another question.

COLD WAR: EXPANSION OF THE HANFORD SITE

Site Name:	Hanford Works - January 1947 to December 1974
Site Manager:	Lt. Col. Fredrick J. Clarke - August 1945 to August 1947
	Carlton Shugg - August 1947 to September 1948
Responsible Agency:	U.S. Army Corps of Engineers
	Atomic Energy Commission - January 1947 to December 1974
Site Contractor:	General Electric Company - September 1946 to January 1964

Rhodes (1986, p. 756) points out that the problem following the war "was not lack of support but lack of authority." Congressional authorization was required before funds could be released. The release of funds was tied to the development of policy objectives and legislation. With the creation of the Atomic Energy Commission, initial legislation and congressional authorization were essentially resolved for the moment. Following the Atomic Energy Commission's introduction into the open political arena, however, the development of a national policy would continually shift with world events and presidential elections.

> ***"Secrecy proved to be a blessing in disguise. Although it dictated remote site locations, required subterfuge in obtaining labor and supplies, and served as a constant irritant to the academic scientists on the project, it had one overwhelming advantage: Secrecy made it possible to make decisions with little regard to normal peacetime political considerations."*** **- Gosling 1999, p. 19**

In an interesting analysis of the United States and Russia at the end of the war, Rhodes (1995, p. 180) compares their relative youth as nations, their shared origin through revolution, and their populations and resources. However, despite their similarities, he concludes that there remains "an intractable difference between them. They were opposite experiments in the large organization of people and natural wealth, the one through liberty and competition, the other through terror and centralized control, an open society and a closed – a crystal of quartz and a crystal of onyx, Robert Oppenheimer once contrasted them – and each was convinced that the other side's intentions were malevolent."

The beginning of the Cold War was neither as abrupt nor as visible as that of World War II. Instead, it grew in the course of boasts and retaliatory statements beginning in 1946 with the Soviet Union's "there can be no permanent peaceful coexistence," Prime Minister Churchill's "an iron curtain has descended across the continent," and the Clifford-Elsey report that Soviet foreign policy was "a direct threat to American security." As a signal of U.S. resolve, the Truman Doctrine, delivered on March 12, 1947, assured the world that the United States would "support free peoples who are resisting attempted subjugation by armed minorities or by outside pressures" (Rhodes 1995, p. 295). In large measure, the Truman Doctrine was the military counterpunch to the Marshall Plan, first articulated by Secretary of State George C. Marshall on June 5, 1947. His economic recovery plan proposed that the United States "do whatever it is able to do to assist in the return of normal economic health in the world, without which there can be no political stability and no assured peace" (Marshall, quoted in Rhodes 1995, p. 297).

With international positions hardening, the Atomic Energy Commission visited each of the Manhattan Project sites early in 1947. David Lilienthal, Chairman of the Atomic Energy Commission, remembered their January inspection "as one of the saddest days of my life" when he determined there was only "one [bomb] that had a good chance of being operable" (Lilienthal, quoted in Rhodes 1995, p. 283). "Meeting early in the year after a whirlwind tour of the production sites and laboratories, the AEC's General Advisory Committee assigned its highest priority to weapons research and production. By February, improvement and expansion of the plutonium production units at Hanford topped the list of AEC goals" (Gerber 1992b, p. 18).

In August 1947, the General Electric Company, having assumed management of the Hanford Site from Du Pont on September 1, 1946, announced that two new reactors would be built and research leading to the development of a new chemical separations process would begin. The news was well received in Richland, whose continued prosperity relied on government support for the Hanford Site.

To enhance plutonium production at a time when the existing reactors were aging, General Electric commissioned construction of the DR and H Reactor complexes to meet Atomic Energy Commission objectives. Completed in March 1949, the DR (D Replacement) Reactor was meant to take the place of the D Reactor, whose graphite core was observed to be expanding and distorting. In fact, expansion was occurring in all three reactors. The distortion was caused by graphite's reaction to intense neutron bombardment. Called "Wigner's disease," after the physicist Eugene Wigner who had predicted the effect in 1942, energy acquired under bombardment realigned the carbon atoms within the graphite's crystal lattice. This rearrangement caused the graphite to expand (Rhodes 1995). Operators monitoring the expansion at B Reactor noted that temperature, in addition to the intensity of the neutron flux, was causing disproportional expansion. As described in the B Reactor HAER in Appendix B on the Internet, "Temperature was so crucial to expansion that the cooler edges of the pile [reactor] were actually expanding quite a bit *more* than the graphite in the highly irradiated but thermally hot center portion." As a consequence of expansion, the process tubes were bowing, making charging and discharging more difficult, the alignments of the control rod and safety rod channels

were altering, and the neoprene seals along the shielding walls were being stressed. Unchecked distortion would render the reactors inoperable or, more ominously, uncontrollable.

Reactor expansion is the reason Groves shut down the B Reactor and reduced the operating power of the D and F Reactors in March 1946. Until the problem was resolved or new reactors were built, B Reactor would be held in reserve. Groves closed B Reactor to ensure that production of plutonium and polonium-210 could continue if D and F had to be taken offline. His primary concern was maintaining a source of polonium-210, which was used as the initiator or trigger in plutonium bombs. To produce polonium-210, "lead-bismuth alloy targets (called 'B Metal') [were] welded…into unbonded aluminum cans," and irradiated in the production reactors. The first targets were fabricated in 1944 in the 313 Building, and production of polonium would continue until the early 1950s (DOE 1997e, p. 158). Polonium-210 is a short-lived isotope. With a half-life of only 138 days, "if the Hanford piles [reactors] broke down and polonium production ceased, the atomic bombs in the nations small stockpile would become unreliable within a year" (Rhodes 1995, p. 277). However, while construction of the DR Reactor was under way, scientists at the Hanford Site's Pile Technology Division found the solution to graphite swelling. By adding carbon dioxide to the helium atmosphere surrounding the reactor, the temperature of the graphite could be raised from 100° C to 250° C. This thermal increase during neutron bombardment within the reactor, termed nuclear annealing, negated the effects of crystal realignment. General Electric restarted B Reactor in July 1948 and elevated the operating power of all three Manhattan Project reactors, which increased product yield. Given this increased productivity, the Atomic Energy Commission held the DR Reactor in standby. The DR Reactor would not be started up until October 1950.

Advancing on the existing design, General Electric engineered the H Reactor to operate at 400 megawatts-thermal – a 60 percent increase in power relative to the B, D, F, and DR reactors. Starting up October 1949, the H Reactor complex was the first post-Manhattan Project site constructed in the 100 Area. It also marked a deviation from the siting plan worked out by Groves and Du Pont in that it was located not downriver from the 100-F Area, as might be expected given the alphabetic sequence established in 1943, but rather up river between the 100-D and 100-F areas. In addition, the DR Reactor was located within one-half mile of the D Reactor so their later simultaneous operation also violated the 1943 siting requirement of a separation of not less than one mile between production reactors. These initial siting requirements would be further abrogated by future expansions.

Construction of two new reactors essentially improved existing capabilities; however, completion of the Plutonium Finishing Plant (234-5Z Building or Z Plant) in 1949 provided an entirely new capability. As described in the ExHPIF for the 234-5Z Building in Appendix B on the Internet: "Although the nitrate compound that left Hanford had been evaporated into a very thick, dry paste for safety reasons, the managing federal agencies (Manhattan Engineer District and later the Atomic Energy Commission) nonetheless viewed the shipment of non-solid forms of Pu [plutonium] as potentially hazardous, and thus looked for a way to create metallic Pu at the Hanford Site."

The expansion ordered in 1947 provided that opportunity. Using plutonium nitrate from the 231-Z Building as feed, operators at the Plutonium Finishing Plant chemically converted plutonium nitrate, the World War II end-product, into hockey puck-shaped plutonium metal "buttons," which resemble hockey pucks. Machinists then fabricated these buttons into "pits" for use in nuclear weapons. Operations began on July 5, 1949, using the Rubber Glove Line, an assembly of 28 interconnected glove boxes. The Rubber Glove Line performed less than satisfactorily. Airborne contamination releases and corrosion failures caused slowdowns and periodic shutdowns at a time when the Atomic Energy Commission was calling for increasing production (see Chapter 2, Section 5 for an extended discussion).

The 234-5Z Building contained its own analytical laboratory where chemists analyzed samples drawn from stages throughout the finishing process to ensure that safety and isotopic standards were maintained. Another section housed the developmental laboratory where researchers sought ways to refine measurement accuracy, extract more plutonium (thereby reducing wastes), and solve production problems (see Chapter 2, Section 5). Support facilities constructed in association with 234-5Z included the 216-Z-1 and 216-Z-2 Waste Cribs, the 241-Z Waste Storage Building, the 272-Z Shop and Warehouse, the 291-Z Stack, the 2701-Z Badge House, the 2704-Z Office Building, the 2705-Z Temporary Technical Office Building, the 2719-Z First Aid Station, and the 2901-Z Elevated Water Storage Tank.

Scientists and politicians alike considered uranium a very limited resource in the late 1940s, so much so that the United States and Great Britain each tried to control the world supply (Rhodes 1995). Dissatisfied with the fact that uranium was flushed away as waste in the initial stages of the bismuth phosphate process, the Atomic Energy Commission issued "direct and urgent orders" to develop a better separations process early in 1947 (Gerber 1992c, p. 84). Consequently, General Electric decontaminated several laboratories within the 3706 Building and assigned their scientists the task of perfecting an alternative process. The scientists labeled the process they invented reduction-oxidation or simply REDOX. In contrast to the bismuth phosphate batch process, REDOX was a continuous, solvent extraction process that was more efficient (in terms of total plutonium extracted per ton of irradiated fuel elements) and more economic (since uranium could be separated out and recovered) (Gerber 1992c, Gerber 1993b). However, construction of the REDOX Plant (202-S Building), the process canyon named after the pioneering chemical separations process, would not begin until late 1949. Chapter 2, Section 4 describes the REDOX process in detail.

To handle the additional waste stream from increased production within the 200 Area, General Electric built the 241-BX, 241-BY, and 241-TX Tank Farms, constructing an additional 42 single-shell tanks (Gerber 1992b). In 1948, General Electric built the 300 North Cribs (321 Cribs). Because monitoring of the main Process Pond determined that radioactivity levels had risen "precipitously, climbing by three to thirty orders of magnitude in water and mud samples taken from 1945 through 1948" (Gerber 1993b, p. 55), the 300 North Cribs were seperated from the 300 Area by nearly 5 miles. A second, larger process pond (the North Process Pond) was constructed that same year after a break in the dike of the main Process Pond (now called the South Process Pond) released 14.5 million gallons of waste water to the Columbia River in 90 minutes (Gerber 1993b)."

The workers who constructed these new facilities during the postwar expansion resided within the 3000 Area, a newly created construction camp located 5 miles north of the Richland Village. Single men lived in barracks acquired from the former Pasco Naval Air Station, while married men lived in small trailers. Some 12,000 construction workers and 13,000 dependents called the 3000 Area camp home in 1948. Population within the Richland Village increased to nearly 23,000 during this expansion period, fueled by "the highest birth rate in the nation!" (Gerber 1992b, p. 22).

The operations workforce alone at the newly renamed Hanford Works expanded from 4479 to 8628 in the 2 years between 1946-1948 (Findlay and Hevly 1995). In their attempt to make Richland "attractive enough to recruit and retain plant employees," the Atomic Energy Commission instructed General Electric that "consistent with security and other requirements, residents…shall enjoy those facilities, services, and activities which are properly a part of American life." Still, to some Richland Village retained its feeling as a police state since the "company, not the citizens, ran the town, and ran it on behalf of the AEC." To act on some of their concerns, General Electric established the Richland Community Council in 1948. The Council "provided a forum for residents to raise questions or propose changes, but it served only as an advisory body, with no legislative power and only a minimal budget provided by GE" (Findlay and Hevly 1995, pp. 80-88). Self-government would not come for another decade.

SOVIET "GIANT" AWAKES: 1947–1949

"In the winter and spring of 1948," Rhodes (1995, p. 317) writes, "the Soviet Union and the Western allies gave up any remaining pretense of continuing their wartime collaboration." New alliances, or forced allegiances, would be formed in the post-war era. Among the first was the alliance between Britain, France, Belgium, the Netherlands, and Luxembourg established by the Treaty of Brussels on March 17, 1948. The occupation of Czechoslovakia by Russian troops on February 25, 1948 was among the first of the Soviet-enforced allegiances (Rhodes 1995).

On June 24, 1948, the Soviets closed all rail traffic leading to Berlin from West Germany, effectively isolating the city. Rhodes (1995, p. 319), citing Soviet sources, proposes that the "possibility that the West might rearm Germany [by including West Germany in a military alliance with the United States, Britain, Canada, and Western Austria] may well have precipitated the Soviet decision to move against Berlin." The State Department had initiated secret discussions on March 22 on establishing a western military alliance with Britain and Canada to defend Western Europe. By mid-June,

with the secret long exposed, the Senate opened the way for "public negotiations towards a North Atlantic Treaty Organization" (Rhodes 1995, p. 322).

President Truman responded to the gauntlet the Soviets had thrown down by approving an airlift operation to supply the American, British, and French sectors of Berlin on June 28. The airlift lasted until the Soviets opened all rail lines in May 1949, 11 months after the crisis began. In one of the first misinformation campaigns of the Cold War, "the government made a point of revealing" that the sixty B-29s the U.S. Air Force flew to East Anglia in support of the airlift in July 1948 "were atomic-capable and hinted that they carried atomic bombs" (Rhodes 1995, p. 326). The allusion was untrue, but the bluff indicated the deterrent effect afforded atomic weapons and foreshadowed the National Security Council's adoption of deterrence as official national policy in November 1948.

Just prior to the Berlin blockade, weapon developers from Los Alamos traveled to Eniwetok atoll to test a new series of bombs, the Mark IV. Norris Bradbury, Oppenheimer's successor at Los Alamos, had directed his staff to develop "small atomic weapons" (Mitchell 1999, p. 21). These small tactical weapons "offered a technological solution that would bring nuclear weapons back to the battlefield, in a sense controlling the awesome destructive capabilities within some acceptable level. The destruction of concentrations of enemy troops, planes, tanks, and ships was morally more acceptable than that of whole cities and their inhabitants" (Mitchell 1999, p. 22).

The Mark IV bombs had new cores, which increased the yield substantially. The *Sandstone* tests of the Mark IV bombs consisted of three explosions: the first of which yielded 37 kilotons, the second 49 kilotons–the largest yield of any atomic weapon yet. The third bomb, tested on May 14, 1948, exploded with a yield of 18 kilotons (DOE 2000a).

Not only were these new cores highly effective, but they were also highly efficient. Using this design, the existing stockpile of nuclear weapons could be upgraded and expanded, and new weapons with higher yields could be added more quickly: "Fabrication of standard nuclear cores stopped immediately so that all fissionable material would henceforth go into new models. The day of tailor-made weapons was fading fast; with Mark 4 would come mass production of components and assembly-line techniques" (Hewlett and Duncan, quoted in Mitchell 1999, p. 22).

At the Conference on Atomic Energy Control held at the University of Chicago in September 1945, Jacob Viner had characterized the United States and the Soviet Union as two giants whose mutual opposition would deter or ignite world conflict (Rhodes 1986, p. 753). Having faced down the Soviets in Berlin and with the West's nuclear capability increasing through expanded production facilities and redesigned weapons, Secretary of State Dean Acheson expressed the administration's general feeling that in July 1949 the "position of the West…[has] grown greatly in strength, and the position of the Soviet Union…has changed from the offensive to the defensive" (Acheson, quoted in Gerber 1992b, p. 23). This feeling was short-lived.

On the isolated, high, short-grass steppes of northeastern Kazakhstan, the Soviets had established a site to detonate their first nuclear device, RDS-1. The test, which the Soviets code-named "First Lightning," was set off at 7:00 a.m. on August 29, 1949. The RDS-1 was a near replica of the Trinity device, whose plans had been acquired through espionage (Rhodes 1995, pp. 167-174). As with Trinity, the test was delayed by light early-morning showers but was successful, exploding with a yield of 20 kilotons. Unlike Trinity, however, the Soviets had constructed single- and multi-story houses, built bridges and tunnels, positioned military hardware, and placed animals both in open pens and within buildings to observe and measure the effects of the explosion and its attendant radiation throughout the test site. Little survived the blast (Rhodes 1995, pp. 364-368). The test marked the culmination of Soviet covert construction operations that had been going on for nearly 4 years.

The Soviets began construction of the F-1 (Physics-1) test reactor in July 1946 based on a design two Soviet scientists, Igor Kurchakov and Igor S. Panasyuk, had proposed in July 1943. However, based on declassified information, physicist Arnold Kramish concluded in 1955 that F-1 "was practically a carbon copy of the American 305 reactor built at Hanford," whose design was being developed at the Metallurgical Laboratory in June 1943 (Kramish, quoted in Rhodes

1995, p. 266). Their function was also identical – testing the purity of graphite and uranium before emplacement within production reactors. It started operation on Christmas day 1946.

Although Stalin did not publicize the success of the "First Lightning" test, western scientists literally pulled the information out of thin air. When a U.S. Air Force "sniffer plane" was on a routine air-monitoring flight over the Kamchatka Peninsula on September 3, 1949, it detected radioactivity "300 percent greater than the level…established as an alert: measurements quickly confirmed that the radioactivity was fission derived" (Rhodes 1995, p. 371). By September 14, experts associated with Los Alamos, the U.S. Navy, and the British monitoring program confirmed these findings. The scientist at Tracerlab concluded that the blast, given the name "Joe 1" by Kramish, had taken place at 6:00 a.m. on August 29 – they were off by one hour (Rhodes 1995). Following a period of denial, skepticism, and guarded acceptance, President Truman made the news public on September 23. The Soviet giant had awakened.

President Truman had made it known on July 14, 1949 before the detonation of RDS-1, that nuclear superiority was paramount to U.S. national security (Mitchell 1999, p. 20). Now that the Soviets had the atomic bomb, his words held a special meaning for Edward Teller, who judged that the time had come to conclude his long-standing push for development of thermonuclear weapons – the "Super." Rhodes (1986, p. 754) explains: "The end sought was a bomb burning about a cubic meter of liquid deuterium. For such a bomb the energy release will be about ten million tons [10 megatons] of TNT." Such a bomb would be 1,000 times more powerful than the one exploded over Hiroshima.

As early as 1943, Teller had lobbied for the development of a hydrogen bomb. Indeed he was "so preoccupied with the idea of the Super during the war-time Manhattan Project that when Oppenheimer assigned Teller work on calculations for Fat Man, the work had to be reassigned" (Mitchell 1999, p. 25). Ernest Rutherford, Marcus Oliphant, and Paul Harteck had discovered the "hydrogen fusion reaction" in 1934 while conducting experiments with the particle accelerator at Cambridge University. When concentrated heavy water (hydrogen-2 or deuterium) was bombarded with deuterium-accelerated nuclei, "the deuterium nuclei had fused together…Neutrons, heat and intense gamma radiation came out of the reaction as…the new nucleus [of helium] adjusted its energy level and stabilized." The reaction required "heating the nuclei until their thermal motion overcame their electrical repulsion" and thereby acquired the name "thermonuclear fusion" (Rhodes 1995, p. 247).

From April 18-20, 1946, the Los Alamos scientist had held a "Super Conference" to review work conducted to date, to debate the feasibility of a hydrogen bomb, and to investigate its design. Teller, summarizing a report he authored with six colleagues, concluded that the Super could be made and that a large-scale development program should be initiated towards that end. Others in attendance were not convinced. The ignition might take place, they argued, but whether or not it would continue to burn was highly problematical. Noting, however, the importance of tritium as a booster for either fission or fusion bombs, Teller recommended its production. This proposal did not generate resistance. The report issued following the Super Conference concluded that development would be costly "using up a fair portion of the national nuclear-weapons budget for some years to come." With the war concluded and with no apparent need for a weapon of this destructive magnitude, research on the Super was restricted to the Theoretical Division and then to only half-time over the next few years (Rhodes 1995, pp. 252-255).

With President Truman's announcement of the Soviet Union's nuclear capability on September 23, 1949 as a catalyst, the Atomic Energy Commission's Joint Committee on Atomic Energy proposed a number of ways to expand the production of atomic weapons including dramatically accelerating work on the hydrogen bomb and building a new generation of reactors so that tritium production would not come at the expense of plutonium production. However, convening the Atomic Energy Commission on October 5, David Lilienthal did not place thermonuclear weapons on the agenda. Incredulous that the hydrogen bomb had been left out of the discussion, Strauss contacted Rear Admiral Sidney Souers, who was to meet with President Truman the following morning. President Truman was briefed on the Super for the first time on October 6, 1949 (Rhodes 1995, pp. 380-381).

On January 31, 1950, President Truman approved development of the Super. National security policy was based on deterrence, and Secretary of Defense Louis Johnson succinctly summarized the implications of that policy with respect to Russia: "We want a military establishment sufficient to deter that aggressor and sufficient to kick the hell out of her if she doesn't stay deterred" (Johnson, quoted in Rhodes 1995, p. 405). Within a few months, two events occurred which made President Truman's decision to add thermonuclear weapons to the U.S. arsenal look prescient. In May, the Communist forces of Mao Tse-Tung expelled Chiang Kai-shek and his Nationalist followers from China. Stalin and Tse-Tung had entered into a mutual assistance agreement on February 14. On June 25, the Communists forces of North Korea invaded the southern Korean peninsula. These events played to the nation's worst fears of unchecked communist expansion.

KOREAN WAR: 1949–1952

Site Name:	Hanford Works - January 1947 to December 1974
Site Manager:	Fred C. Schlemmer - September 1948 to May 1950
	David F. Shaw - June 1950 to June 1955
Responsible Agency:	Atomic Energy Commission - January 1947 to December 1974
Site Contractor:	General Electric Company - September 1946 to January 1964

"Using the Korean War as a club," the Senate persuaded President Truman to increase Atomic Energy Commission funding from $260 million to $1.4 billion between July and October 1950. A National Security Council Special Committee report, issued on October 2, cited the need not only for "more weapons of existing designs, but for new designs in large numbers," and focused attention on their delivery systems as well. By mid-1951, the Joint Committee on Atomic Energy was already pressing for an additional enhancement of 50 to 150 percent in atomic weapons production (Mitchell 1999, p. 31).

Gerber (1992b, p. 25) has characterized the period from late 1949 to 1952 as "the greatest era of expansion in U.S. atomic/nuclear history." During this interval, the Atomic Energy Commission consolidated uranium metal production at the Fernald Feed Materials Production Plant in Ohio; constructed a second plutonium production site, the Savannah River Plant, in South Carolina; and constructed a second uranium enrichment site, the Paducah Gaseous Diffusion Plant, in Kentucky. Two new laboratories, the Reactor Testing Station in Idaho and the Sandia Laboratory, were opened. The Pantex Plant in Texas was established as a weapons assembly site. Finally, the Atomic Energy Commission established the Nevada Test Site and expanded the Pacific Proving Ground at Bikini and Eniwetok atolls (Gerber 1992b). At the same time these new sites were being constructed, the Atomic Energy Commission added a number of facilities to the existing Manhattan Project sites.

Workers broke ground for the C Reactor complex, the sixth production reactor at the Hanford Site, on June 6, 1951. It started up 17 months later on November 18, 1952. Like its predecessors, the C Reactor was a single-pass, water-cooled, graphite-moderated reactor. Unlike its predecessors, however, the design team engineered it to operate at 650 megawatts-thermal, which was a 60 percent increase over the design rating of the H Reactor completed only a year earlier and a 160 percent increase over the original design specifications for the Manhattan Project reactors (Gerber et al. 1997, p. 5.17). To accelerate construction, General Electric located the C Reactor within the 100-B Area and less than a mile from the B Reactor to "take economic advantage of existing utilities, services, and facilities" (Gerber 1993a, p. 106).

Nonetheless, as production capabilities rose at the Hanford Site, the Atomic Energy Commission production requirements expanded even more. To meet ever-spiraling demands, Hanford Site physicists looked for ways to increase power levels first within the Manhattan Project reactors and then all reactors. In April 1949, physicists began incremental testing at D Reactor that would push the operating level from 250 to 330 megawatts-thermal. The D Reactor was chosen because with the DR Reactor nearly complete, the D Reactor was considered expendable should something go wrong. Exceeding expectations, D Reactor was operating at 400 megawatts-thermal by January 1950 (Gerber 1993a).

> ***"To increase plutonium production capacity, Hanford began adding low-enriched uranium fuel slugs [elements] to its reactors as early as 1950. Enriched uranium fuel also allowed Hanford engineers to even out the reactor's temperature and power distribution, reducing problems caused by uneven thermal expansion and radiation-induced swelling of the graphite core. Neutron absorbing "poison" slugs, also made on site, also helped to even out the reactor's power distribution. Most of these enriched uranium slugs were manufactured using the same techniques as the natural uranium slugs. However, some of the fuel elements were made of highly-enriched uranium alloyed with aluminum, which required special fabrication techniques to prevent accidental criticalities."*** **- DOE 1997e, p. 154**

Sensing that operating levels could be pushed further, the Atomic Energy Commission recommended that the Hanford Site scientists "test whether B, D, and F Reactors could operate at 600 megawatts-thermal, without causing undue system failures or increases in the plutonium-240 content of the product." Design reviews necessary to identify what equipment changes would be required to reach this level began shortly thereafter (Gerber 1993a, p. 4). However, the increased operating level was already causing problems as "fuel element ruptures, feared since World War II, became a reality." The first fuel failure occurred in the F Reactor in 1948. Subsequent failures "increased slowly during 1949 to 1950, but expanded dramatically in 1951" (Gerber 1993a, p. 26). Chapter 2, Section 3 discusses in detail the failure of fuel elements that resulted from increasing the power levels.

In constructing the C Reactor and extending the power levels of the existing reactors, General Electric increased plutonium production capabilities at the Hanford Site and supported the Atomic Energy Commission's immediate need to meet escalating military requirements. Augmentation in plutonium production also allowed General Electric to support development of the Super from February 1949 to March 1952 by releasing some of the process tubes in the existing reactors for tritium production. Production of tritium gas, conducted under the code name "P-10," began with the jacketing of lithium-aluminum alloy target elements in unbonded aluminum-silicon cans in the 313 Building. Initially manufactured offsite, machinists began to fabricate these target elements on the Hanford Site in the mid-1950s. The lithium targets, "surrounded by highly enriched uranium 'driver' elements," were irradiated primarily in "H Reactor but sometimes in B Reactor" (Gerber 1993a, p. 44). The irradiated targets were stored in the 104-B-2 Tritium Laboratory to await processing. To process the tritium, General Electric converted the four-story 108-B Chemical Pump House into offices, laboratories, and operations support rooms and installed five process lines contained within exhaust hoods on the third floor. A 300-foot ventilation stack was added to the 108-B Pump House to exhaust process gases. Tritium gas was extracted from the irradiated target elements, bottled in shipping casks, and then stored in the 104-B-1 Tritium Vault. The 1703-B Technology Service Building was also constructed to provide additional offices as well as storage space for process equipment (Gerber 1993a, pp. 44-46).

With plutonium production levels rising and after nearly 5 years of developmental testing at the Hanford Site, the REDOX Plant (202-S Building), the "only continuous solvent extraction plant in the world," began processing irradiated fuel elements in January 1952 (Gerber 1992b, p. 25). Chemists in the 222-S Control Laboratory provided process sampling and operations support not only for plutonium separation work conducted in the REDOX Plant but also for uranium recovery work in the 221-U and 224-U plants and waste reduction operations in the 242-B and 242-T Waste Evaporator buildings as well. With REDOX operational, General Electric shut down B Plant (Gerber 1994a).

Responding to the need to conserve, recover, and recycle uranium (a strategic material believed to be scarce at this time), General Electric modified the 224-U Bulk Reduction Building in 1951 to serve as the primary facility for the Uranium Metal Recovery program. Now known as the Uranium Trioxide Facility or simply UO_3, it began full-scale operations in 1952 to convert liquid uranyl nitrate hexahydrate (UNH) to uranium trioxide powder (UO_3) through a calcination process (Bailey and Gerber 1997, p. 13). The uranium fraction (UNH), isolated during REDOX separations, was piped to the Uranium Trioxide Facility for processing. A second uranium feed for the 224-U Bulk Reduction Building came from an unanticipated source. In 1952, General Electric changed the mission of the U Plant from training operators for B and T Plants to extracting the uranium contained within the bismuth phosphate process waste stored in the single-shell tank

farms. General Electric retrofitted the process cells in the U Plant with new equipment to accommodate the tri-butyl phosphate process, developed by Hanford Site chemists, to effect separation (Gerber et al. 1997). The Atomic Energy Commission supplied the uranium trioxide powder to the defense program for use in armor plating, projectile tips, and nuclear submarine fuel among other items.

A program to extract a formerly discarded material – uranium within high-level liquid waste – not only met a strategic need but also indicated the ongoing efforts to manage waste generated at the Hanford Site. The 242-B and 242-T Waste Evaporator Buildings represented another program aimed at waste reduction. General Electric constructed these facilities in 1951 to increase the storage capacity of the high-level liquid waste storage tanks by decreasing the amount of liquid contained in the waste. Operators first pumped liquid waste from the single-shell storage tank to a feed tank within the 242 Building. From the feed tank, the liquid waste passed to one of two preheaters before entering the evaporator tank. Continued heating in the evaporator tank concentrated the waste by boiling off liquid, leaving behind a slurry. This slurry was pumped back into the storage tanks where it solidified as it cooled. The net result was a reduction in waste volume. Low-level liquid condensate was disposed of in cribs or trenches while liquid vapor was scrubbed, filtered, and vented through an exhaust stack (see the 242-T HPIF in Appendix B on the Internet for additional information). Despite these efforts, General Electric constructed an additional eighteen single-shell, high-level liquid waste storage tanks (241-S and 241-TY Tank Farms) because of the increased productivity requirements the Atomic Energy Commission mandated.

At the same time that liquid wastes were being recycled and reduced, Hanford Site scientists were investigating ways to control or limit airborne releases of radionuclides from the process canyon stacks. Increasing production goals and expanding production capabilities placed additional burdens on the existing chemical separations facilities. Before the REDOX Plant opened, B Plant and T Plant were supporting five reactors operating at increased output levels. Not surprisingly, the emission of process gases had risen with each production quota. By late 1947, scientists had documented contaminated vegetation over a wide area of Idaho, Oregon, and Washington that was linked to emissions from the 291-B and 291-T Stacks.

After nearly 2 years of operations, General Electric installed water scrubbers between the exhaust fans and the stack openings and within the exhaust ducts for each process cell to filter the air before it was released. General Electric also replaced the fans, fan casings, and ductwork within the stacks because of radiologically contaminated particulates or "specs" being emitted with the exhaust gases (Gerber 1994a, p. 33). Further modifications were made to the exhaust flow in 1948 when General Electric added large underground sand filters to treat process gases before their release through the stacks. Measuring 110 feet long by 48 feet wide, these filters were designed to strip radiologically charged "droplets" or "acid mists" (formed from condensed process gases) as well as particulates out of the waste stream. However, "these filters were only marginally successful because the sand beds plugged and the resistance (pressure drop) within the unit increased rapidly" (Gerber 1994a, p. 34). Fiberglass filters installed within the dissolver off-gas lines offered little additional improvement. Finally late in 1950, Hanford Site scientists discovered that fiberglass embedded with silver-nitrate ("silver reactor" filters) was 99.9 percent effective in capturing iodine-131 when placed in the ducts between the dissolver cells and the main exhaust lines. However, this success rate was achieved only when the silver reactor filters were replaced or regenerated frequently and irradiated fuel cooling periods were extended to 80-100 days before dissolving (see Gerber 1994a, pp. 33-37 for additional discussion).

Operating conditions in the Soviet Union during this time provide perspective for waste management practices in the United States. In commenting on working conditions within the Soviet Union's chemical separations plant at Chelyabinsk-40, Rhodes observes:

> *"It was impossible to work at the plutonium separation plant without dangerous radiation exposure. Sixty-six percent of B installation workers received subclinical but excessive doses in the first year of operation of up to 100 rem; an unlucky 7 percent received above 100 rem where clinical signs such as vomiting and blood changes begin to appear. (For comparison, the average lifetime dose of workers in the US and British nuclear-*

weapons industry has been estimated at from 3 to 11 rem.).... B installation, by design, discharged its intensely radioactive fission waste directly into the Techa River. By 1951, radioactivity from Chelyabinsk-40 had been measured in river water discharging into the Arctic Ocean more than a thousand miles north." - Rhodes 1995, pp. 350-351

These statements highlight a philosophical difference underlying the two nuclear weapons development programs. The Soviets viewed the general workforce as largely expendable and gave little weight to environmental damage in their design considerations. From its inception, the U.S. program implemented measures to monitor worker health and safety while seeking ways to first understand and then limit environmental degradation. This is not to imply that the U.S. program always succeeded in these objectives or that the consequences of ill-informed decisions are not still with us. It does demonstrate, however, that the United States was aware of at least some of the potential dangers, investigated their effects, and, when not rushed to action, sought to act accordingly. The Hanford Site offers a case in point.

Applied research, as well as production capabilities and process improvement, benefited from increased funding during the first years of the Korean War. The Hanford Site Biology Program had outgrown the facility assigned to it in 1946 – a single Quonset hut in the 100-F Area. Responding to a 1948 budget request from Hanford Site administrators, the Atomic Energy Commission Advisory Committee for Biology and Medicine determined that "it was unwise to set up an additional national laboratory at Hanford as it was primarily a production center and research in biology and medicine there should be directly applicable to local problems. Nevertheless, the Committee believed it highly desirable that adequate facilities should be provided for aquatic biology and for a farm for animals because of specific concern to operations at Hanford" (see the 108-F Building ExHPIF in Appendix B on the Internet). In 1949, the Hanford Site Biology Program acquired the remodeled 108-F Chemical Pump House for office and laboratory space and constructed an animal farm and agricultural plots nearby. New radioecology and aquatic biology laboratories were added in 1951, with additional expansions in 1953 and 1956 devoted to biological research. Scientists concentrated on three major research areas: biological effects of reactor effluent on native fish within the Columbia River, biological effects of radioisotopes (such as cesium-137, iodine-131, and strontium-90) on living tissue within large and small animals, and botanical effects on plants grown in soils containing radionuclides.

The Atomic Energy Commission was not the only agency expanding its presence at the Hanford Site. In response to increased tensions due to the escalating Cold War as expressed by the active conflict in Korea, the U.S. Department of Defense initiated additional measures to address the security of U.S. nuclear facilities. On March 28, 1951, the Army established Camp Hanford in North Richland and assigned troops from Ft. Lewis the task of providing air defense for the Hanford Site. The Army built sixteen anti-aircraft artillery (AAA) batteries, encircling the primary production complex, along what came to be called Army Loop Road (Gerber et al. 1997, p. 5.47). Each AAA site was equipped with 90 mm and 120 mm guns placed in four revetments constructed from sandbags. Each site also contained barracks for the enlisted men and officers and support facilities such as radar facilities, a mess hall, a motor pool, and craft shops.

Camp Hanford, situated in the 3000 Area just south of the North Richland Construction Camp, "consisted of cantonment/barracks areas, an administrative area, commercial district, a trailer park, 'Bremerton' housing (residential units from the Puget Sound Naval Shipyard in Bremerton, Washington), medical facilities, recreation centers, and an industrial area" (Gerber et al. 1997, p. 5.26). The Camp Hanford industrial area, located at the southern terminus of the Camp, contained an electronic and signal maintenance shop (1154 Building), brigade motor pool (1226 Building), ordnance maintenance and crafts fabrication shop (1240 Building), and shipping and receiving warehouses (1250 and 1252 Buildings) among other facilities that provided support for the defense installations (Gerber et al. 1997, p. 5.48). Chapter 2, Section 9 describes Camp Hanford and its 10-year mission.

KOREAN WAR: 1952–1955

With the Korean War continuing, President Truman approved further expansion on January 16, 1952. At $4.9 billion, this authorization was 250 percent higher than the 1950 appropriation and indicated the exponential growth of the Atomic Energy Commission under its new Chairman, Gordon Dean. The "atomic weapons program was now so large that in the fall of 1952 the hitherto insatiable [Atomic Energy Commission] Military Liaison Committee reported that it found no reason for further expansion" (Wells, quoted in Mitchell 1999, p. 33). All installations and improvements carried under this authorization were due for completion by January 1957.

On September 24 and October 18, 1951, the Soviets had detonated their second ("Joe 2") and third ("Joe 3") atomic bombs, which were smaller, lighter, and more powerful than their first (Rhodes 1995). That same fall, with Stanislaw Ulam having found a way to make the Super work and fearful the Soviets might be making equal advances, the Atomic Energy Commission pressed forward with a dedicated thermonuclear weapon program. The Panda Committee, headed not by Teller but by Marshall Holloway, had 1 year to deliver a workable bomb. Teller left Los Alamos in September 1951 in protest. Primarily in response to Teller's unending efforts to establish a second weapons laboratory after leaving Los Alamos, the Atomic Energy Commission opened the Livermore Laboratory in California in July 1952. Although no longer a member of the design team, Teller now had a place to conduct thermonuclear diagnostic research (Rhodes 1995).

> ***"Once the explosion broke through the casing, it expanded in seconds to a blinding white fireball more than three miles across (the Hiroshima fireball had measured little more than one-tenth of a mile) and rose over the horizon like a dark sun; the crews of the task force, thirty miles away, felt a swell of heat as if someone had opened a hot oven, heat that persisted long enough to seem menacing…At its furthest extent, the Mike cloud billowed out above a thirty-mile stem to form a huge canopy more than one hundred miles wide that loomed over the [Eniwetok] atoll. Radioactive mud fell out, followed by heavy rain…The fireball had vaporized the entire [Elugelab] island, leaving behind a circular crater two hundred feet deep and more than a mile across filled with seawater…The explosion vaporized and lifted into the air some eighty million tons of solid material that would fall out around the world."*** **- Rhodes 1995, pp. 508-509**

The nuclear community grew on October 3, 1952 when the British exploded their first atomic bomb ("Hurricane") with a yield of 25 kilotons (Rhodes 1995). Just under a month later, the balance of power shifted dramatically when the United States detonated the world's first thermonuclear bomb. At 7:15 a.m. on November 1, 1952, "Mike" ("The Sausage") exploded with a yield of 10.4 megatons, the equivalent of 20 billion pounds of TNT – twice as much as "all the explosives used during the Second World War" (Rhodes 1995, p. 494).

The transitions of 1952 were not limited to nuclear armaments. Nikita Khrushchev assumed nominal control of the Soviet Union on June 26, 1952 following Stalin's death that March. After losing the New Hampshire primary in the spring of 1952, President Truman withdrew from the presidential race. His successor as the democratic candidate, Adlai Stevenson, lost to Dwight D. Eisenhower that November. Close on the heels of these political transitions, the Soviets detonated their first thermonuclear bomb ("Joe 4") at the Semipalatinsk test site on August 12, 1953. The explosive yield of 400 kilotons, fewer than the Atomic Energy Commission's Ivy series fission bomb, indicated that the Soviets had not discovered or through espionage knew of the Teller-Ulam invention of staging and fission compression (Rhodes 1995). However, because the Soviet device was thermonuclear, it was sufficient to alter again the perception of the balance of power and reinvigorate the arms race.

On January 12, 1954, John Foster Dulles, Secretary of State under President Eisenhower, announced the administration's national policy of "massive retaliation," which anticipated the use of "nuclear weapons, tactical as well as strategic, whenever their use would be desirable from a military standpoint" (Mitchell 1999, p. 36). For the first time, the use of nuclear weapons was placed on a par with that of conventional arms and as an acceptable response to conventional aggression. In part, this policy was foreshadowed in a memorandum from President Eisenhower to Dulles in September 1953. Assessing Soviet aggressiveness, President Eisenhower advised that "our own preparation could no longer be geared to a policy that attempts only to avert disaster during the early 'surprise' stages of a war, and so gain time for full mobilization. Rather, we would have to be constantly ready, on an instantaneous basis, to inflict greater loss upon the enemy than he could reasonably hope to inflict on us" (Eisenhower, quoted in Rhodes 1995, p. 528).

Interestingly, President Eisenhower had told Lewis Strauss, upon appointing him Chairman of the Atomic Energy Commission in May 1953, that his first assignment was to demilitarize atomic energy so the world would no longer have to live with the fear of a nuclear war (Rhodes 1995). President Eisenhower would translate this message into action under his "Atoms for Peace" initiative. However, his defense policy of retaliation had the opposite consequence. It opened the floodgate of nuclear weapons development and deployment. The Atomic Energy Commission budget rose again from $4.9 billion in 1952 to $9 billion in 1955, an amount "exceeding the capital investment of General Motors, Bethlehem and US Steel, Alcoa, Du Pont and Goodyear combined" (Rhodes 1995, p. 561): "More production capacity meant more weapons, which diversified from strategic bombs into tactical and strategic warheads attached to everything from depth charges to atomic cannons to anti-aircraft missiles to ballistic missiles of every range from battlefield to intercontinental" (Rhodes 1995, p. 561).

By 1952, the Joint Chiefs of Staff had identified from 5,000-6,000 nuclear targets, nearly 100 times the 66 cities that had been marked in 1945. Initially, the number of targets was a function of the number of weapons in the nuclear stockpile. But with improved bomb designs extracting greater yields from a lower quantity of fissile material and greatly expanded production capabilities, the number of targets became the driving force and production responded accordingly (Rhodes 1995).

As part of "Project X", General Electric began building the KW and KE reactors – the largest single-pass, water-cooled, graphite-moderated reactors constructed at the Hanford Site – in November 1952 and January 1953, respectively. While the Atomic Energy Commission and General Electric knew by the early 1950s that heavy-water or beryllium would serve as a better moderator, they returned time and again to the graphite-moderated, single-pass, water-cooled reactor design because the nation needed plutonium and the proven design guaranteed results. With the KE and KW Reactors, General Electric carried the design to a second-generation status by dramatically increasing the scale. At 1850 megawatts-thermal, their design was for a power operating level three times that of the C Reactor and nearly nine times higher than the original Manhattan Project reactors. Each core contained 3220 process tubes and more experimental ports than any of the other reactors (Gerber et al. 1997, p. 5.17). The KW Reactor started up in December 1954 and the KE Reactor in February 1955.

Further abrogating the siting requirements Lieutenant General Groves established in 1943, General Electric sited the KW and KE reactors within the same area (100-K Area), less than a mile apart, and approximately halfway between the "two other twin reactor sites, B/C and D/DR." Their decision to co-locate the KW and KE reactors downplayed "the possibility of a simultaneous accident," focusing instead on their "rapid, economical construction" (Findlay and Hevly 1995, pp. 168-169).

At the same time, General Electric continued to increase the power levels of the existing reactors to meet rising production demands. For example, by 1956 "a thorough set of modifications and retrofittings designed to increase coolant flow to the pile [reactor]" had raised the operating level at B Reactor to 800 megawatts-thermal (Gerber 1993a, p. 21). These changes involved all facets of the water treatment, delivery, and circulation system so that 71,000 gallons

per minute could be pushed through the reactor (Gerber 1993a). Before the reactors were shut down, their operating levels would be pushed far higher, some to nearly ten times their design rating.

With augmented irradiation capability came the need for increased separations capability. Workers completed construction of the Plutonium-Uranium Extraction (PUREX) Plant (202-A Building) in April 1955. This was the last chemical separations canyon built at the Hanford Site. Like the KE and KW "jumbo" reactors, PUREX would become the "workhorse" separations plant both because of its design capacity and the increased efficiency of its extraction process. PUREX used a continuous solvent extraction process similar to the REDOX process. However, rather than relying on gravity to maintain the countercurrent flow of solutions within the extraction columns, the PUREX Plant used piston-driven pumps to circulate solutions within pulsed extraction columns. Extraction solvents of the two processes also differed. The PUREX process used tri-butyl phosphate rather than hexone. The PUREX process also separated a greater number of products including both weapons-grade and fuel-grade plutonium, depleted and slightly enriched uranium, neptunium, and thorium (see Chapter 2, Section 4 for more information on PUREX). The PUREX Plant went on line in January 1956. Because of the combined efficiency of REDOX and PUREX, T Plant, which by 1953 was reduced to processing only 12 percent of the fuel being irradiated in the 100 Areas, ceased processing altogether on March 20, 1956 and received a new mission (Gerber 1994a).

The REDOX complex also expanded during this period. One of the more significant additions was the Plutonium Concentration Facility (233-S Building) constructed in 1955 "as part of the REDOX Canyon and Service Facility's Phase II capacity increase" (Gerber et al. 1997, p. 5.39). Using an ion-exchange process, operators produced a final solution with a higher plutonium concentration level than had been achieved before. This solution was transported to the 234-5Z Plutonium Finishing Plant for final processing (see the 233-S HAER in Appendix B on the Internet for detailed discussion).

In 1952, operators de-emphasized use of the Rubber Glove Line in the 234-5Z Plutonium Finishing Plant and on March 18 began operations on the world's first large-scale Remote Mechanical Line, known as the RMA Line. The switch from manual to mechanical operations immediately increased production rates by 200 percent. General Electric retired the Rubber Glove Line in May 1953. To accommodate spiraling Atomic Energy Commission production demands, General Electric installed two machining glove boxes on the RMA Line so that two separate weapon pits could be produced simultaneously. By September of that year, Hanford Site plutonium was also being sent directly to the Rocky Flats Plant northwest of Denver for final fabrication. Hanford Site operators met or exceeded all Atomic Energy Commission production quotas for finished pits and non-machined buttons throughout 1954 and 1955 (see Chapter 2, Section 5 for additional details).

Like the uranium recovery process initiated at the UO_3 Facility in 1952, Hanford Site chemists pioneered a process "to recover plutonium from PFP waste streams" in the 234-5Z Building (Gerber et al. 1997, p. 5.40). Beginning in 1951, researchers in the 1706 and 321 Buildings, and later the 325 Building, contributed to the development of the RECUPLEX (RECovery of Uranium and PLutonium by EXtraction) process. RECUPLEX, a dissolver/solvent extraction process conducted in three glove boxes, coaxed plutonium from solid and liquid waste streams derived from the plutonium finishing operations. From July 1955 to May 1962, RECUPLEX operators provided highly concentrated plutonium-nitrate solutions to the RMA Line for conversion to plutonium metal, thereby adding hundreds of kilograms of plutonium to the U.S. nuclear arsenal (see Chapter 2, Section 5).

In 1955, General Electric also added the 224-UA Building, containing "six continuous-action calciners," to the UO_3 Facility (224-U Building) to "improve powder- and waste-handling" capabilities for the Uranium Metal Recovery program (Bailey and Gerber 1997, p. 13). Liquid uranium nitrate, obtained initially from REDOX and subsequently from PUREX as well, was now concentrated in the 224-U Building and converted to uranium oxide powder in the 224-UA Building (Gerber et al. 1997, p. 5.35).

Given increased production efficiency and demands, workers constructed twenty-one additional single-shell, high-level liquid waste storage tanks (241-SX and 241-A Tank Farms) in the 200 Area between 1953 and 1955.

General Electric opened five new research and development laboratories and a second test reactor facility within the 300 Area at the Hanford Site between 1952 and 1955. In Findlay and Hevly's opinion (1995, p. 146), research at the Hanford Site fulfilled two overriding objectives, the "steady development of graphite-moderated reactors" and the discovery of "measures to avoid production losses." "Hanford's first eight reactors were graphite and water-moderated, water-cooled uranium piles [reactors]; they were recognized by the end of World War II as dead ends in terms of the development of nuclear reactor technology. But they remained throughout the Cold War as cost-effective, reliable sources of plutonium, and ironically the U.S. strategy of a high-technology defense mandated that Hanford stick to a relatively low-technology method of producing plutonium" (Findlay and Hevly 1995, p. 141).

The largest of the research and development laboratories was the 325 Radiochemistry Building, dedicated to chemical separations process improvement. As completed in 1953, this facility contained eight hot cells, "each 6 feet by 6 feet by 5.5 feet (deep) surrounded by 2.5-foot-thick concrete walls with stainless steel liners [designed] to safely house and handle multicurie-level chemical development work with high-activity substances" (Gerber 1993b, p. 21). With its completion, much of the research formerly conducted in the 3706 Building transferred to the 325 Building. Scientists in the 325 Building worked to improve the PUREX, REDOX, and UO_3 processes; to lower the activity levels of chemical separations waste; and to develop the RECUPLEX process (Gerber 1992b, 1993b).

The 326 Pile (reactor) Technology Building, completed in 1953, had two primary missions, one relating to reactor physics, the other to metallurgy. "Experimentation with higher power levels, new lattice configurations, and cooling methods and trials with varied materials and designs in process tubes and fuel elements were proceeding quickly and simultaneously" (Gerber 1993a, p. 27). Continuing the research initially conducted in the 189-D Building, scientists in the 326 Building pushed the leading edge in Approach-to-Critical studies in developing lattice configurations that not only increased productivity but also improved safety. Lattice configuration, "the spacing of fuel tubes and moderators within the pile [reactor]," was of critical importance because their arrangement was the primary determiner of reactivity and, therefore, power (see the 305-B ExHPIF in Appendix B on the Internet). In addition to lattice configuration, scientists also examined reactor components and fuel elements to effect improvements using "[s]olid-state nondestructive examination (NDE) methods." Another area of metallurgical research included analyses to improve fuel element jacketing and thereby reduce fuel failures (Gerber 1993a, p. 27).

To accelerate reactor design studies and relieve the burden then being placed on the 305 Test Pile (reactor), General Electric completed the subsurface component of the 305-B Experimental Test Reactor Building in 1954. Two small reactors were housed in this below-grade structure. Both were dedicated to improving lattice configuration. The Physical Constants Test Reactor (PCTR) began operations in October 1955. Physicists used the graphite-moderated PCTR to test experimental lattice designs and measure their efficiency. The second test reactor, the Thermal Test Reactor (TTR), a 5-foot graphite cube, was acquired in 1954 from the Knolls Atomic Power Laboratory but was not placed in service until 1957-1958 (Gerber 1992c, p. 72). Physicists used the TTR "as a neutron source for an external thermal column, as a low power irradiation facility, or for danger co-efficient measurements" in conducting a variety of exponential reactor physics experiments (see the 305-B ExHPIF in Appendix B on the Internet).

While scientists worked primarily with unirradiated materials in the 326 Building, scientists in the 327 Radiometallurgy Building (operational in 1953) worked with "hot" materials to understand and resolve the problems such as fuel element distortion, uranium growth, and process tube corrosion that accompanied increased power levels.

> ***"Irradiated materials, including ruptured or failed fuel rods [elements] containing plutonium and fresh fission products, were examined while they were "green" (i.e., when they had experienced very little decay or stabilization time). Destructive examination of an irradiated fuel rod called for drilling a pinhole from which was collected a fission gas sample. Next the element was sawed open, and a metallurgical sample was ground and polished for analysis. Irradiated process tubes and other reactor components likewise were cut, ground, and polished to produce workable samples."*** **- Gerber 1993a, p. 31**

Scientists conducted destructive and non-destructive analyses in the 327 Building's eight hot cells and two basins. The 327 Building replaced the 111-B "Test Building" where Hanford Site scientists had first initiated studies "to determine the 'nature and causes of dimensional instability' in fuel elements and the effects of irradiation stresses on pile [reactor] materials" (Gerber 1992c, p. 154).

Concurrent with these studies on materials and process improvement, General Electric built the 329 Biophysics Laboratory in 1953 "to support the pioneering…environmental monitoring and bioassay programs that were developed at the Hanford Site during the 1940s and 1950s" (Gerber 1993a, p. 24). Scientists working in this facility developed new radiation counting procedures as well as the instrumentation necessary to conduct the analyses. They examined air, water, soil, vegetation, and terrestrial and marine wildlife samples from areas within and adjacent to the Hanford Site to as far away as the Pacific Proving Grounds. Hanford Site scientists also played "a major role in monitoring and counting fallout from atmospheric nuclear bomb tests conducted by the United States and the USSR" (Gerber 1993a, p. 24).

To support these laboratories, General Electric built the 328 Mechanical Development Building to fabricate and service the "specialized and intricate apparatus and equipment" that the biologists, chemists, metallurgists, and physicists working in the 325, 326, 327, and 329 buildings used. The only repairs not conducted in the 328 Building were those involving contaminated equipment that had to remain within the "hot" laboratories. The 328 Building, opened in 1952, replaced the Manhattan Project 3717 Instrument Shop and the two 3722 Area Shops (Gerber 1993a, p. 47).

The 618-10 Burial Ground… ***"consisted of trenches and rows of burial caissons known as "pipe fields." The caissons were made of 5 to 6 open-bottomed 55-gallon drums welded together and buried upright. From the mid-1950s until about 1960, solid radioactive wastes were collected from operations buildings in cardboard containers and then stored in lead pans known as "gunk catchers" and transported to 300 North [618-10] in shielded "load luggers." The cardboard waste containers then were dropped from the gunk catchers down the caissons, and the holes were filled with sand and dirt until radiation levels declined to a safe or "tolerance" reading. If radiation levels could not be reduced to tolerance ranges, concrete was poured down the hole until such levels were achieved." -*** **Gerber 1993a, p. 59**

Liquid radioactive wastes from these laboratories were piped to sampling tanks in the new 340 Retention and Neutralization Building through a complex of "single-walled stainless steel pipes" known as the Radioactive Liquid Waste System. Technicians sampled the waste within these tanks and diverted wastes with no detectable radioactivity to one of two newly constructed Liquid Waste Trenches (307 Structures). Waste registering higher than allowable release limits was pumped into holding tanks to await tanker truck transport to 200 Area cribs (Gerber 1993a, p. 57). High-level radiochemical and radiometallurgical solid wastes, primarily from the 325 and 326 buildings, were disposed of first to the 618-2 Burial Ground in 1953 and then to the 618-10 Burial Ground, located more then 4 miles northwest of the 300 Area, from 1954-1964.

Following the expansions of 1949-1955, the Hanford Site produced more than twice as much weapons-grade plutonium per year as the Savannah River Site through 1967 (Figures 6 and 7 in DOE 1996b). It is likely, though unsubstantiated pending release of production amounts from non-U.S. facilities, that the Hanford Site produced more weapons-grade plutonium than any other complex in the world.

PEAK PRODUCTION: 1956–1965

The Killian report, named after James Killian, President of the Massachusetts Institute of Technology, whom President Eisenhower appointed to head the Technical Capabilities Panel in 1954, reached Eisenhower early in 1955. The report recommended "crash programs on intercontinental ballistic missiles (ICBM), intermediate-range ballistic missiles (IRBM) based in Europe and on submarines, new military communications systems, intelligence systems, dispersal of Strategic Air Command (SAC) bombers with some portion on continuous airborne alert, and new antiballistic missiles to destroy (as yet undeveloped) Soviet missiles" (Mitchell 1999, p. 37). In short, the report reflected the growing

paranoia of a Soviet surprise attack and the measures necessary to survive and counter it. This fear was amplified in 1956 when Khrushchev warned the West on November 17, "We will bury you."

In the spring of 1957, President Eisenhower asked H. Rowan Gaither to lead a panel of the Science Advisory Committee of the Office of Defense Mobilization in evaluating civil defense needs. Gaither's deputy, Robert C. Sprague, was successful in expanding the scope to include investigation of a "ready and effective second-strike capability" as well. That fall the Soviets placed the first man-made object into outer space with the launch of Sputnik I on October 4, 1957 (Mitchell 1999). "Sputnik, meaning "fellow traveler" in Russian,…was technologically crude and uninteresting to those involved in the U.S. space program, and had no military value, but the nation was horrified, in a state of near panic" (Mitchell 1999, p. 38).

The Soviets now appeared capable of delivering nuclear warheads in minutes from space rather than in the hours required to deliver bombs by conventional aircraft. The United States had not demonstrated this ability. The Gaither report, issued to President Eisenhower on November 7, 1957 and largely authored by Sprague and Paul Nitze, played up the "spectacular progress" made by the Soviets with respect to nuclear weapons and asserted that the Soviets had "probably surpassed" the United States in missile technology. The report recommended that an additional $44.2 billion be added to the defense budget over 5 years to address this "missile gap." In briefing Eisenhower, Sprague did not believe the President understood the gravity of the Soviet threat. However, Mitchell argues that "Eisenhower had the military background to know that wars tend to be initiated during periods of tense international crises, rather than bolt-from-the-blue scenarios, especially one of such magnitude as to involve nuclear weapons." Displeased with President Eisenhower's equivocal response to the report, "some members of the Gaither committee leaked the highly classified report to the press, creating the sensationalism and public outcry that they thought would bring action" (Mitchell 1999, p. 40).

By May 1958, the Soviets had also launched Sputnik II and Sputnik III, and "near-hysterical descriptions of Soviet nuclear capabilities and threats" figured prominently in the national and highly partisan debate leading to the 1960 presidential election (Mitchell 1999, p. 41). Based on high-resolution aerial photographs taken by U-2 spy planes and knowledge that the U.S. military missile program would be operational by 1960, President Eisenhower knew that the claims of Soviet superiority and the charges being leveled against his administration of providing a "second-best defense" were unfounded. However, his inability to release this top-secret information may have contributed to Nixon's defeat. "Ironically," Mitchell (1999, p. 43) points out, "this two-year period (1958-1959) of near-hysterical demand for nuclear weapons…was in fact the two-year period of greatest U.S. stockpile growth in the entire history of the arms race."

Having won the election, John F. Kennedy learned the true nature of the U.S. nuclear weapons force as well as intelligence estimates of the vastly over-extolled Soviet stockpile. However, his campaign had raised public expectations and created a momentum for increased armament. Of more immediate concern, he discovered that the Navy and the Air Force were engaged in a power struggle to shape and control the nuclear weapons program.

With the launch of the U.S.S. George Washington, the world's first submarine both nuclear-powered and armed with sea-launched ballistic missiles in May 1960, Admiral Arleigh Burke recommended that the administration adopt a deterrence-based strategy using "submerged nuclear-powered submarines with free roam of two-thirds of the earth's surface." The Air Force, on the other hand, put forward a war-fighting strategy, developed by RAND analyst William Kaufmann, that relied upon "more accurate land-based missiles and aircraft-delivered bombs" (Mitchell 1999, pp. 45-47). Robert McNamara, Secretary of Defense under President Kennedy, had commissioned a study earlier from his staff to investigate strategic alternatives. This report was delivered shortly after both the Navy and Air Force had briefed McNamara on the strengths of their plans and the weaknesses of the other's. Acting on the recommendations made by his staff, McNamara established "…a new nuclear war plan that would emphasize destroying enemy military forces, avoiding their cities and protecting a ready reserve force aimed at their cities but withholding this force as a bargaining lever with which to coerce the enemy to end the war and come to terms favorable to the United States" (Mitchell 1999, p. 49).

In adopting this policy, the Kennedy administration largely aligned itself with the Air Force's position that the United States could not only fight a nuclear war but win it. McNamara referred to this policy as "flexible response." To succeed in these policy objectives, the United States would have to continue investing heavily in the nuclear stockpile. "Swept up in a political current of their own making, both Kennedy and McNamara approved additional spending on nuclear weapons and delivery systems for what McNamara would later admit was an already over-built stockpile" (Mitchell 1999, p. 51).

Two pivotal events in the early 1960s set the temperature of the Cold War for the next two decades: the erection of the Berlin Wall and the facedown over nuclear missiles in Cuba. In "practicing diplomacy by nuclear threat" (Rhodes 1995, p. 569) throughout the 1950s, the United States and the Soviet Union gained experience in intimidating each other across the globe. The two superpowers rattled missiles and bombers in closing out the Korean War in 1953, at the Suez Canal in 1956, and over Lebanon and the islands of Quemoy and Matsu in 1958. The world had become divided ideologically, and nowhere would this be demonstrated more clearly than in Berlin. Three years after demanding that the forces of the North Atlantic Treaty Organization leave West Berlin and to stem the "hemorrhage of East Germans defecting to the West" (Rhodes 1995, p. 570), Khrushchev erected the most visible and psychological symbol of the Cold War in 1961 – the Berlin Wall. Indeed, the destruction of the Berlin Wall on November 11, 1989 generally marks the end of the Cold War.

The hottest point of the Cold War occurred during the week of October 22-28, 1962. On October 14, a U-2 flight photographed Soviet/Cuban construction of medium-range ballistic missile (MRBM) sites in western Cuba. Khrushchev meant to counter the U.S. placement of fifteen Jupiter MRBM missiles in Turkey by deploying Soviet MRBMs in Cuba. In his own words, Khrushchev maintained, "We had no desire to start a war. On the contrary, our principal aim was only to deter America from starting a war" (Khrushchev, quoted in Rhodes 1995, p. 570). But the war he sought to avoid came closer to occurring that week than at any other point in time.

While Kennedy and Khrushchev "began an exchange of belligerent messages" (Rhodes 1995, p. 572), the U.S. military, by presidential order, moved from Defense Condition (DefCon) 5 to DefCon 3 with President Kennedy's nationally televised announcement of the crisis and his intention to blockade Cuba on October 22. Following that address, the nation was "gripped by dread of a nuclear holocaust. Schoolchildren were practicing duck-and-cover drills" (Thomas 2000, p. 55). By October 24, the military stood at DefCon 2, a state of full alert, and war seemed imminent. The crisis peaked that day as the U.S. Navy stopped two Soviet freighters at the quarantine line. Upon receiving the news that the blockade had held, Secretary of State Dean Rusk issued one of the most oft-quoted phrases of the Cold War, "We are eyeball to eyeball, and I think the other fellow just blinked" (Thomas 2000, p. 56). The crisis concluded on Sunday, October 28, with Khrushchev's announcement to the Soviet Presidium that "In order to save the world, we must retreat" (Thomas 2000, p. 59). "The Soviet Union never went to full nuclear alert in all the years of the Cold War. After the Cuban missile crisis, the United States never did again. Nor did the two nations ever again directly confront each other" (Rhodes 1995, p. 576).

> ***"Security depends upon assuming a worst plausible case, able to absorb the total weight of nuclear attack on our country – on our retaliatory forces, on our command and control apparatus, on our industrial capacity, on our cities, and on our population – and still be capable of damaging the aggressor to the point that his society would be simply no longer viable in the twentieth-century terms. That is what deterrence of nuclear aggression means. It means the certainty of suicide to the aggressor, not merely to his military forces, but to his society as a whole."*** **- McNamara quoted in Mitchell 1999, p. 54**

Lee Harvey Oswald assassinated President Kennedy on November 22, 1963. Lyndon Johnson assumed the presidency that day retaining McNamara as his Secretary of Defense. This continuity was meaningful because McNamara had an opportunity to rethink the war-fighting strategy while reflecting on the events in Berlin and Cuba. McNamara's belief in an ability to inflict significant damage on Soviet nuclear forces sufficient to avert massive U.S. civilian casualties

through retaliatory strikes began to wane with the Soviet deployment of submarine-launched missiles and the confirmed existence of their land-based silos in 1962. His resolve diminished further with receipt of mathematician Glenn Kent's systems analysis review of "flexible response" in January 1964. Kent concluded that "offense will always win over defense" in a nuclear war and will do so "at a lower cost." He demonstrated, conclusively to McNamara at least, that "fighting and winning a nuclear war is virtually impossible"(Mitchell 1999, p. 53). Given these realizations, McNamara effected a shift in U.S. policy to a deterrence-based strategy referred to as "assured destruction."

Mitchell (1999, p. 55) argues that this change in philosophy, together with the diversion of defense funds to the emerging war in Vietnam, President Johnson's overall frugality, and his focus on domestic policy led to the "first ever leveling-off and eventual decline in the U.S. nuclear weapon stockpile." In McNamara's view, the United States had far surpassed the number of weapons necessary to ensure the destruction of the Soviet Union. In his State of the Union Address, delivered on January 8, 1964, President Johnson announced a number of cutbacks for the Atomic Energy Commission – the closure of three Hanford Site plutonium production reactors was among them (Mitchell 1999).

> ***"Weapons complex configuration and weapons design and manufacturing processes in the U.S. [had] changed substantially from the Manhattan Project era. Laboratories and production plants developed better technologies to increase their capabilities, output, and efficiency. The weapons themselves [had] evolved considerably, becoming smaller, lighter, more powerful and versatile, safer, and more reliable. The federal government centralized the weapons complex in the early 1950s. By the mid-1960s, stockpiles of some key weapons materials became plentiful enough that the complex ceased producing them."* - DOE 1997e, p. 117**

RISE AND FALL OF DEFENSE PRODUCTION

Site Name:	Hanford Works - January 1947 to December 1974
Site Manager:	James E. Travis - June 1955 to June 1965
Responsible Agency:	Atomic Energy Commission - January 1947 to December 1974
Site Contractor:	General Electric Company - September 1946 to January 1964

Essentially, the military used both the "massive retaliation" and "flexible response" strategies "to justify larger and larger procurement budgets, and consequently more and more nuclear weapons" (Mitchell 1999, p. 50). With "assured destruction," McNamara eliminated "damage limitation and counterforce as a military rationale for more weapons" since a "still greater nuclear superiority could not be theoretically justified" (Mitchell 1999, pp. 53, 55). Figure 1.7 shows the effects of these policy decisions. Atomic Energy Commission production of weapons-grade plutonium on the Hanford Site rose dramatically from 1956 to 1960, reached a sustained peak between 1960 and 1965, then dropped off from 1966 through 1969 even more precipitously than it had risen.

In 1961, the year before the standoff over missiles in Cuba, the Hanford Site workforce produced the most weapons-grade plutonium of any year—almost 4500 kilograms (Figure 6 in DOE 1996b). In the Hanford Site's peak production years of 1956-1965, the workforce produced 37,146 kilograms of weapons-grade plutonium—almost 70 percent of the total amount produced between 1945-1989.

General Electric continuously raised the operating levels of the production reactors between 1956 and 1964 to meet the ever increasing military demands for plutonium. By the time the Atomic Energy Commission ordered closure of the original Manhattan Project reactors, they had attained operating levels nearly ten times their initial design rating at 2210 megawatts-thermal (B Reactor), 2165 megawatts-thermal (D Reactor), and 2140 megawatts-thermal (F Reactor). The early post-war reactors were operating at 2140 megawatts-thermal (H Reactor) and 2015 megawatts-thermal (DR Reactor), while the Korean War reactors had attained operating levels of 2500 megawatts-thermal (C Reactor) and 4400 megawatts-thermal (KW and KE reactors) (DOE 1996b). All of these operating levels were several orders of magnitude above their design ratings. The numbers for the "jumbo" reactors might have gone higher still but the Atomic

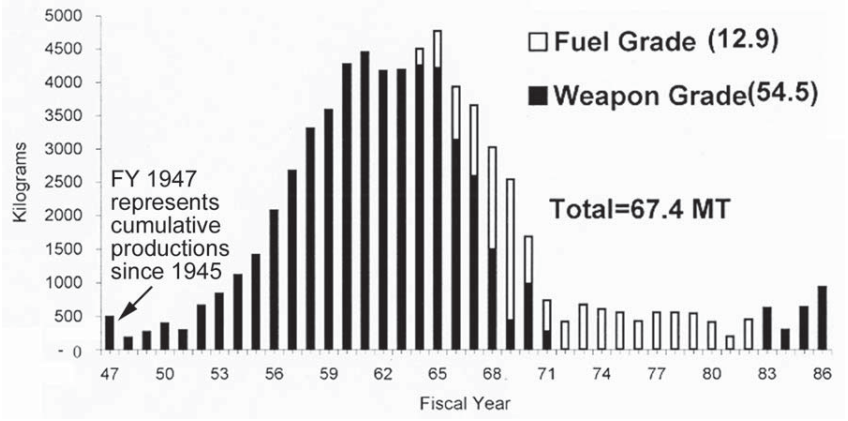


Figure 1.7. *Total Annual Production of Plutonium at the Hanford Site*

Energy Commission imposed "an administrative power limit of 4000 megawatts-thermal at the KE and KW-Reactors" (DOE 1996b, Section 9.1.1). General Electric achieved these operating levels by investing heavily in cooling, electrical, and mechanical improvements to the older reactors and their support facilities as well as modifications in fuel element design and process tube fabrication (Gerber 1993a, pp. 62-63).

Gerber (1993a, p. 62) attributes most of the power increase to a new fuel element design introduced in 1957. In fabricating internally and externally cooled fuel elements (known as I&E fuel), technicians in the 313 Building machined a horizontal hole through the uranium metal to allow water to circulate around and within the fuel element simultaneously as it passed through the reactor. The internally and externally cooled fuel "had a vastly augmented cooling capacity" and "provided less hydraulic resistance to the coolant flow." In a related improvement, General Electric began to use zircaloy-2 to replace the original aluminum process tubes. The higher tensile strength and higher melting point of zirconium made the new process tubes both thinner, thereby increasing heat exchange and water volume, and safer in the event of water loss (Gerber 1993a). Adding to these engineering changes, General Electric also effected an environmental change:

> *"Another innovation that allowed higher operating power levels in the late 1950s and early 1960s, specifically in the hotter summer and autumn months, was artificial cooling of the Hanford Reach of the Columbia River by a controlled spill of cold water from the bottom levels of Lake Roosevelt, the reservoir behind the Grand Coulee Dam. The cooling program began during the summer of 1959, and continued through the summer of 1965. It cooled the Columbia's water in the vicinity of Hanford reactors by an average of 1° C, and by a maximum of 2.3° C during September 1960. The lower inlet water temperature made possible higher power levels in reactor operations, while still not exceeding the maximum bulk outlet temperatures that were allowed."* - Gerber 1993a, p. 62

Pushing the Hanford Site reactors did not come without consequences, however, as the higher operating levels brought more frequent and more serious fuel ruptures, accelerated process tube corrosion and failures, and increased leaks in the effluent pipes among other problems. Hanford Site scientists investigated ways to reduce or eliminate these problems in the 185/189-D Complex and the 300 Area research laboratories. For example as early as January 1952, scientists had initiated "heat transfer and fuel corrosion studies" in the newly converted 185/189-D Building, "a thermal hydraulics and coolant systems development studies facility" (Gerber et al. 1997). According to the 190-D Complex HAER in Appendix B on the Internet, using mock-ups of pipes and tubes loaded with dummy fuel elements, scientists within the 185/189 "Flow Lab" developed "coolant flow information that allowed repeated power level increases in the Hanford reactors."

Exhaust gases also increased in volume as reactor operating levels rose. To address this rise in emissions, General Electric constructed large, primarily below-grade filters in the early 1960s to treat process gases before their release through the reactor stacks. The 117 Air Filter Buildings, consisting of two filter cells divided by an operating gallery, were tied into the existing exhaust ductwork using concrete inlet and outlet tunnels. Engineers designed "an exhaust filtration system that would entrap a small percentage of the pile [reactor] noble gases (kryton-85, argon 39, 41, and 42, and xenon-133), 70 to 95% of the halogens (iodine-131 and bromine-82), and most of the remainder of the particulates and aerosols in reactor gases (including cesium-137, tellurium-129, selenium-79, ruthenium-103/106, and others)" Gerber 1993a, p. 67). Technicians monitored the exhaust gases using instrumentation placed in the 119 Air Sample Buildings. Prior to this time, reactor gases had not been filtered before being dispersed into the atmosphere.

The Atomic Energy Commission placed equal pressure on the Savannah River Site to produce beyond its engineered capacity during this period. With an original design rating of less than 500 megawatts-thermal, "the thermal power level of the reactors was increased to approximately 2500 mw" between 1955 and 1965 (DOE 1996b, Section 9.1.2). Indeed, the Atomic Energy Commission demanded increased productivity throughout its nuclear weapons complex during this interval.

Hanford Site chemical separations operators met the challenge of increased plutonium production from the site's eight enhanced reactors with only two operating canyons (REDOX and PUREX), although the real ability to meet accelerated demand rested primarily with PUREX. Engineers had designed PUREX to operate at a processing capacity of 8.33 metric tons of uranium per day. Within its first year of operations, PUREX staff had pushed operations to 16 metric tons of uranium per day, twice the design rating. By 1958, PUREX accounted for 79 percent of the Hanford Site production total. In the fall of 1960, in just under 5 years of operations, PUREX "reached the point of having processed 22,000 tons of irradiated fuel, thus surpassing the combined total of B and T plants and the REDOX facility for all their years of operations. For short periods of time, PUREX demonstrated the capacity to operate at 3.6 times its design capacity" (Gerber 1996, p. 4-14). This production rate notwithstanding, General Electric re-engineered the process equipment first between 1959 and 1961 and then again in 1965 to bring operations to 33 metric tons of uranium per day (Gerber 1996).

Responding to the need to increase efficiency to further production, General Electric modified the RMA Line in the 234-5Z Building in 1955 so that the "precipitation and purification activities" formerly conducted in the 231-Z Building would now be the first steps undertaken at the Plutonium Finishing Plant (Gerber 1996, p. 5-3). This action concentrated plutonium finishing within one building, thereby increasing efficiency, and eliminated the need for twice handling and transporting plutonium between the chemical separations and metal production phases, thereby increasing safety. Typical of the Hanford Site, the 231-Z Building did not stand idle following this loss of function. General Electric partially restructured the building's interior and established the Plutonium Fabrication Laboratory. Scientists working in this facility conducted "specialized plutonium metallurgy work…associated with research for the development of more sophisticated nuclear weaponry. Research was also conducted in the facility that was associated with plutonium fuels development for the commercial nuclear industry" (Gerber et al. 1997, p. 5.37).

General Electric further accelerated production by installing the Remote Mechanical C (RMC) Line in the Plutonium Finishing Plant in 1960. The RMC Line, "a completely self-contained, remotely operated series of glove boxes," produced both plutonium metal and machined weapons parts. Operating the RMA and RMC Lines in tandem, technicians provided the Atomic Energy Commission with weapons components of "precise, specified dimensions and configuration" (Gerber 1996, pp. 5-2 to 5-4) until December 1965 when the AEC shut down machining operations at the Hanford Site and transferred this task to the Rocky Flats Plant.

General Electric sought to contain or control the wastes generated by plutonium finishing operations. The RECUPLEX process was one of the measures they applied. However, a criticality incident in April 1962 resulted in the permanent shutdown of the facility. Prior to this closure, engineers had been designing a "safer and a more flexible version of the RECUPLEX." Completed in December 1963 and operational by May 1964, operators in the Plutonium Reclamation Facility (236-Z Building) used a continuous solvent extraction process to recover and purify plutonium from plutonium-bearing scrap materials generated at the Plutonium Finishing Plant. The resultant plutonium nitrate was then returned to the PFP for processing (Gerber et al. 1997, p. 5.40). Using industrial solid waste rather than process waste as feed material, operators in the 232-Z Incinerator Building burned and/or leached plutonium-bearing waste materials generated across the Hanford Site to recover usable plutonium, which they returned to PFP beginning in January 1962. General Electric also constructed the 242-Z Waste Treatment Facility to recover plutonium from the liquid waste generated in the Plutonium Finishing Plant and contained in the 241-Z Tanks. Recovery operations began in 1963 (Gerber et al. 1997, p. 5.41).

Given the production rates attained by the PUREX Plant, General Electric built four additional single-shell, high-level liquid waste storage tanks (241-AX Tank Farm) in the 200 East Area. These tanks, the last single-shell tanks constructed at

the Hanford Site, were available to receive PUREX process wastes from 1963-1964 (Gerber 1992b). The total number of single-shell tanks containing high-level liquid waste now stood at 149 (see Gephart 1999 for current information on liquid waste tanks at the Hanford Site).

Following 2 years of chemical cleaning that had begun with an initial nitric acid wash on April 1, 1956, General Electric placed T Plant into service as the Hanford Site's central decontamination facility in 1958. Although decontamination operations began that year, cleanup continued through 1969 as workers removed most of the chemical separations processing equipment and buried it within solid waste burial grounds near T Plant. In 1959, General Electric added the 2706-T Decontamination Annex to handle "equipment too large to be moved into T Plant or pieces having lower contamination levels than those decontaminated in T Canyon itself" (Gerber 1994a, p. 39). In addition to cleaning Hanford Site equipment and returning it to service, an activity that netted between $100,000 and $200,000 in monthly savings, decontamination workers also processed offsite materials including "high-exposure, irradiated fuel from the Shippingport (Pennsylvania) power reactor" in the late 1970s and the "zeolite beds…loaded with cesium-137 from the Three Mile Island (Pennsylvania) power reactor" in 1983 (Gerber 1994a, p. 42). Limited Operations status was imposed in January 1987 and remained in effect until both the 221-T Plant and 2706-T Decontamination Annex were inactivated in January 1990 awaiting major upgrades.

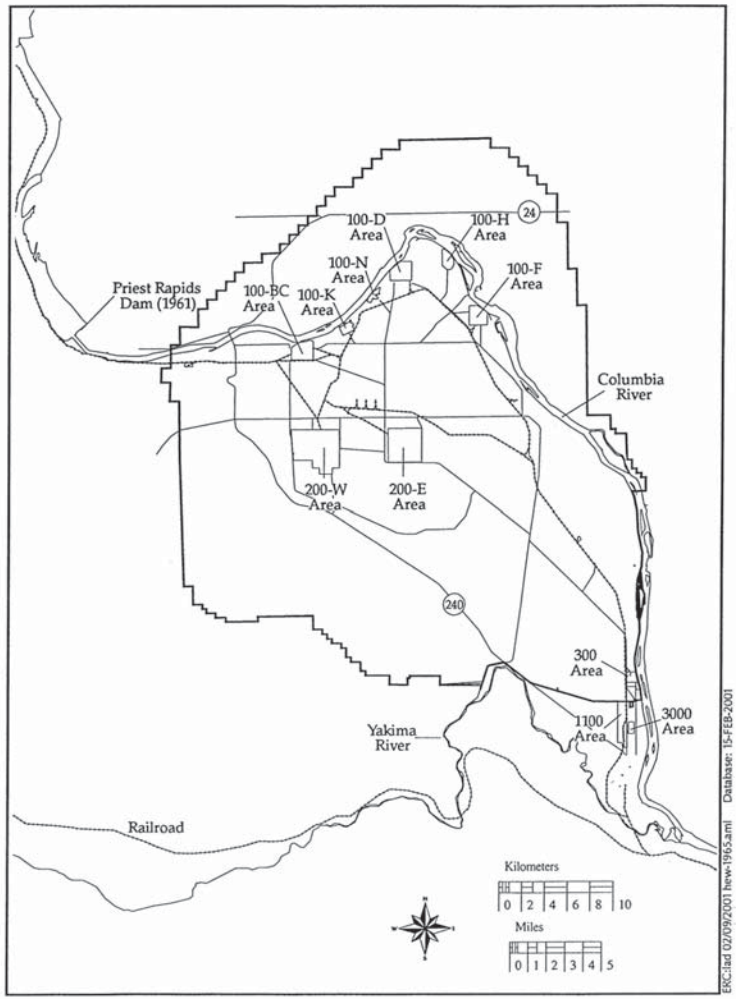


Figure 1.8. *Hanford Site during the Cold War Era Around 1965 When the Site Was Called Hanford Works*

It was during the period of peak plutonium production (the 1960s) that General Electric built the ninth and final graphite-moderated, water-cooled production reactor at the Hanford Site, the N Reactor. Figure 1.8 shows the additional reactor areas, roads, and Priest Rapids Dam added since the time of the Manhattan Project. The Atomic Energy Commission advanced the N Reactor (originally referred to as the New Production Reactor and then just N Reactor) as a model to demonstrate the "technological and economic feasibility of constructing a dual-purpose reactor capable of producing special nuclear materials for weapons and also using the steam for electricity" (Stapp and Marceau 1996, p. 18). Senator Henry Jackson of Washington, a member of the Joint Committee on Atomic Energy, was the driving force behind the Atomic Energy Commission's position. In fact, by arguing in 1956 that there could never be enough atomic bombs, Findlay and Hevly (1995, p. 171) suggest that Jackson used the Senate "to force a reluctant AEC to build a dual-purpose reactor at Hanford." Arguments for and against construction were long and embittered, and in 1958 Congress approved only those funds sufficient to construct a weapons-production reactor, albeit a safer one incorporating new design technology.

Engineers designed another significant difference into the cooling system for the N Reactor. Abandoning the single-pass design for the first time, General Electric incorporated a recirculation configuration. This design change accounted for a number of benefits. First and foremost, "innovation of the light-water

> ***"A significant difference from the Hanford [Site]'s earlier reactor was N Reactor's change from a positive-void coefficient design to a far superior negative-void coefficient design. When a steam bubble, or void, develops in any one of the process tubes, the neutron flux increases logarithmically and enhances the possibility of a serious nuclear accident. N Reactor's design incorporated a negative-void coefficient that, in the case of a steam bubble or void in the process tube, tends to shut the reactor down."* - Stapp and Marceau 1996, p. 23**

recirculation design configuration greatly reduced the direct release of radionuclides to the environment" since the primary cooling water was not directly discharged to the Columbia River. Because recirculation required that the water be pressurized, higher operating levels were attainable with less film deposited in the process tubes due to higher flow rates. Since less water was necessary under pressurized conditions, a smaller water intake system would suffice. Finally, the "recirculation design also enabled the generation of steam to produce electricity" (Stapp and Marceau 1996, p. 23). "By putting the water in the pipes under a pressure of 3206 pounds per square inch, the water could be prevented from turning to steam and superheated water could be run through a heat exchanger to provide steam for a generating plant…" (Findlay and Hevly 1995, p. 170).

To meet the startup deadline, the reactor operators started up N Reactor on December 31, 1963 and immediately shut it down. Actual startup of operations was in March 1964, and it was several years before it operated in its dual capacity of producing both plutonium and steam for electricity.

The N Reactor, "having benefited from nearly two decades of experience with Hanford's eight older reactors," was fueled by a new type of fuel element fabricated through a new process developed in the 306 Fuel Element Pilot Plant. Constructed in 1956, General Electric used the 306 Building to "pilot process improvements in single-pass reactor fuel fabrication methods" (Gerber 1993b, pp. 7-8). Anticipating the operation of the N Reactor, General Electric expanded the facility in 1960 and assigned its staff the task of developing a fuel element that could withstand increased heat and pressure. Rising to the challenge, Hanford Site metallurgists pioneered a "coextrusion fabrication process" wherein "all the fuel-element components, including the uranium core and all the cladding materials, were cleaned, assembled, and then extruded together. This method provided a better, more uniform bond than the earlier process of jacketing each fuel element separately" (Gerber 1993b, p. 7). Besides the process improvement, N Reactor fuel elements were also composed of two pieces, an inner and outer element, designed as a "tube-in-tube configuration (with a hole running down the entire length of the element)," which "allowed cooling water to circulate optimally around the elements" (Gerber 1993b, pp. 7-8). Machinists began making the fuel elements in the 333 Fuels Manufacturing Building, originally known as the New Fuel Cladding Facility, in 1960 (see Chapter 2, Section 2 for a detailed discussion of the process and facilities).

Because the Hanford Site was the leading producer of weapons-grade plutonium for the Atomic Energy Commission, its air defense remained critical. In 1955, the U.S. Army placed four Nike Ajax missile complexes on the Hanford Site. These guided missiles replaced the AAA gun batteries since the missiles provided "an air defense system with the capacity of engaging high speed aerial targets at greater ranges than conventional antiaircraft artillery." Three systems were emplaced on the North Slope, the area north of the Columbia River and south of Saddle Mountain. The fourth system was placed at the base of and atop Rattlesnake Mountain. By the late 1950s, a more advanced Nike missile, the Hercules, replaced the Ajax series. This replacement was short-lived, however, as "the development of the intercontinental ballistic missiles had rendered Nike missiles obsolete, and the Nike sites were abandoned when Camp Hanford was deactivated in 1960 and closed in 1961" (Gerber et al. 1997, p. 5.47).

Budgetary considerations and an abundance of formerly scarce nuclear materials resulted in a shift from redundant sites to single-mission sites and a shutdown of some sites and materials production facilities in the mid-1960s (DOE 1997e, p. 18). For example, the Atomic Energy Commission eliminated the production of plutonium weapons parts on the Hanford Site in 1965 leaving the Rocky Flats Plant as the sole source of plutonium components (DOE 1997e, p. 26).

More significant than the loss of a function, the Hanford Site began to loose its primary mission when the Atomic Energy Commission began shutting down the production reactors. Following President Johnson's announcement of cutbacks, the Atomic Energy Commission ordered the closure of the DR Reactor, effective December 1964, and closure of H and F reactors effective April and June 1965, respectively. The Atomic Energy Commission would issue additional closure orders in 1967, 1968, and 1969.

EMERGENCE OF NON-DEFENSE APPLICATIONS: ATOMS FOR PEACE

In December 1953, President Eisenhower announced his "Atoms for Peace" initiative designed to share "technology and nuclear material with other nations, including nuclear materials for research and power reactor programs." Before this could happen, however, Congress had to amend the Atomic Energy Act of 1946. They did so in 1954. The amendment allowed "civilian peaceful use, though not ownership, of special nuclear materials" and further allowed "U.S. assistance to foreign countries developing peaceful nuclear programs" (DOE 1996b, Section 3.1). With this amendment, President Eisenhower acted on his own directive to Lewis Strauss, delivered on Strauss' appointment as chairman of the Atomic Energy Commission, to develop alternatives other than military applications for atomic energy. In 1957, the International Atomic Energy Agency was formed "to promote peaceful nuclear energy and control nuclear material" (DOE 1996b, Section 3.4). "The mid-to-late 1950s was a very expansive time in United States nuclear history. The belief was widespread that atomic energy would be the fuel of the future adopted to virtually all civilian and industrial power needs" (Gerber 1993b, p. 33).

In 1949, the Atomic Energy Commission had established the National Reactor Testing Station (now known as the Idaho National Engineering and Environmental Laboratory) northwest of Idaho Falls, Idaho. This facility offered an isolated location to design, build, and test prototype nuclear reactors. In the 1950s and 1960s, the Atomic Energy Commission charged the facility staff with developing nuclear power for peacetime use and finding methods to effectively deal with radioactive waste (DOE 1997e). The Atomic Energy Commission had not selected the Hanford Site for the initial Materials Testing Reactor in 1952 because the reactor "was designed to be used by researchers for research; a secondary group and a secondary function at Hanford, as its role was defined by the AEC." The Atomic Energy Commission built the Materials Testing Reactor in Idaho because they viewed the Hanford Site as a "professional workplace dominated by engineers rather than scientists, and, among the scientists, by the most industrially-oriented disciplines" (Findlay and Hevly 1995, pp. 150-151). By 1960, the Hanford Site scientific community was not content to let this assessment persist.

Knowing both the importance of and the opportunities afforded in developing, testing, and fabricating alternate fuels for commercial applications, General Electric completed construction of both the 308 Plutonium Fabrication Pilot Plant (PFPP) and the 309 Plutonium Recycle Test Reactor (PRTR) in the 300 Area in 1960. "Anxious to participate in this new atomic frontier," Hanford Site scientists then "embark[ed] on a large research effort…directed at demonstrating the effectiveness of various plutonium oxide and mixed (plutonium, uranium, and other metallic) oxide fuel blends" (Gerber 1993b, pp. 33, 36). Scientists working on the Plutonium Fuels Utilization Program developed and fabricated plutonium-based fuel elements in the PFPP, first in metallic form and then as "ceramic fuel blends ('cermets')," from 1960 through 1965 (Gerber 1993b, p. 36). They tested these "developmental fuels" in the PRTR, "a heavy water moderated, 100 megawatt experimental reactor" used not only to test alternative fuels but also "process tubes, and the physical parameters of plutonium fuels" (Gerber 1992b, p. 40). Design engineers had located the PRTR partially below grade within the 309 Building containment vessel. In addition to three large, below-grade cells containing reactor process, experimental, and instrumentation equipment, the 309 Building also contained a subsurface Hot Fuel Examination Facility, an irradiated fuel storage pit, and a fresh fuel storage pit (Gerber 1993b, p. 33). Scientists had pre-tested many of the PRTR components using mock-ups in the 185/189-D Thermal Hydraulics Laboratory. Between 1968 and 1972, physicists used the High Temperature Lattice Test Reactor, a 10-foot cubed, liquid nitrogen gas-cooled, graphite-moderated reactor housed in the 318 Building, "to test powdered, pelletized and other experimental fuels at high temperatures" (Gerber 1992b, p. 40).

In 1960, General Electric also completed construction of the 325-A High-Level Radiochemistry Annex to further "innovative, non-defense" research programs. This addition to the 325 Building provided three large hot cells within

which scientists conducted "pioneering" isotope separation work for the National Aeronautical and Space Administration and medical researchers. Using high-level liquid waste as source material, chemists "fractionized specific isotopes [strontium-90, cesium-130, curium-244, americium-241, and promethium-147 being most in demand]…by ion exchange, carrier precipitation, solvent extraction, and various combinations of these and other methods" (Gerber 1993b, p. 23). Chemists in the 325 Building complex also investigated methods to encapsulate strontium fluoride and cesium chloride and to vitrify high-level wastes in support of waste treatment and waste management objectives (Gerber 1993b).

The Atomic Energy Commission authorized the 324 Chemical Materials Engineering Laboratory (constructed between 1964 and 1966 and originally named the Fuel Recycle Pilot Plant) to provide "chemical reprocessing and metallurgical examination" services for fuel elements irradiated in the PRTR. A second mission was to "house the Waste Solidification Engineering Project, one of the first high-level waste vitrification demonstration programs in the world" (Gerber 1993b, pp. 48-49). Therefore, design engineers provided both hot cells and laboratories for radiochemical and radiometallurgical research as well as numerous "cold" laboratories, a maintenance and fabrication shop, storage vaults, and waste vaults throughout the multi-level building. The support mission for PRTR ended quickly, however, when PRTR shut down in 1969 following the Atomic Energy Commission's decision to terminate mixed oxide fuels research (Gerber 1993b, p. 36). Several "contamination events" associated with PRTR operations likely contributed to this decision to shut down the test reactor (see Gerber 1993b, pp. 35-36 for discussion). On the other hand, vitrification research, using "[e]xtremely high-level waste, sometimes 'spiked' with extra strontium-90," or, post-1975, "spent commercial reactor fuel," continued until 1980 (Gerber 1993b, p. 51).

Hanford Site scientists began to prepare "plutonium oxides in specified, tailored blends for commercial nuclear experiments and development" within the Plutonium Finishing Plant in September 1964. The European Atomic Energy Community (EURATOM) was the customer. Between 1966 and 1968, non-defense work climbed to nearly 30 percent of the workload at the Plutonium Finishing Plant as "large-scale interaction with the commercial nuclear industry, nuclear research customers and foreign nuclear customers became a reality." After 1968, the RMA Line, closed since 1966, became known as the "oxide line" because of its use in non-defense work (Gerber 1996, pp. 5-4 to 5-5).

COLD WAR ENDS: DIVERSIFICATION AT THE HANFORD SITE

The end of the Cold War was not nearly as simple or as linear as the following discussion may suggest. The geopolitics were very complex. The period from 1960-1990 witnessed the rise of the Chinese as a nuclear power (October 16, 1964) and thermonuclear power (June 17, 1967), the emergence of oil as a defining force in world commerce, numerous proxy wars within the "Third World," the introduction of Soviet troops in Afghanistan, and a host of other domestic and international events that shaped and contorted the times. The interested reader is directed to *The Cold War, A History* by Martin Walker (1995) and the sources the author draws on for a detailed accounting.

The Cold War may have ended with the breakup of the Soviet Union in 1991, but glimpses of its demise can be seen in retrospect over a 30-year period in efforts to control the deployment and use of nuclear weapons. Having walked to the brink of nuclear war and measured its consequences, representatives of the United States, Great Britain, and the Soviet Union met during July 1963 to negotiate a comprehensive test ban treaty. When onsite inspections became an insurmountable obstacle, negotiators turned to a limited test ban that would outlaw nuclear tests in the atmosphere, under water, and in outer space. President Kennedy signed the Limited Test Ban Treaty on July 25, 1963. He addressed the American public the following night and expressed his desire to effect a thaw in the Cold War.

> *"In an age when both sides have come to possess enough nuclear power to destroy the human race several times over, the world of communism and the world of free choice have been caught up in a vicious circle of conflicting ideology and interest. Each increase in tension has produced an increase of arms; each increase of arms has produced an increase of tension…Yesterday, a shaft of light cut into the darkness…For the first time an agreement has been reached on bringing the forces of nuclear destruction under international control – a goal*

first sought in 1946 when Bernard Baruch presented a comprehensive control plan to the United Nations…If we are to open new doorways to peace, if we are to seize this rare opportunity for progress, if we are to be as bold and farsighted in our control of weapons as we have been in their invention, then let us now show the world on this side of the wall and the other that a strong America also stands for peace. There is no cause for complacency." - Kennedy 1963

On July 1, 1968, sixty nations signed the Nuclear Arms Nonproliferation Treaty, and on November 17, 1969, the United States and Soviet Union began Strategic Arms Limitation Talks.

The U.S. Senate ratified the Limited Test Ban Treaty by an 80 to 14 vote on September 24, 1963. The Treaty went into effect on October 11. President Kennedy had come a long way from his campaign rhetoric.

Under President Johnson, McNamara had found a way to reverse defense spending on nuclear weapons. In fact, he approved research and development for only one new weapon system, the Multiple Independently-targetable Reentry Vehicle (MIRV) as a way to "approve military requests for additional weapons without the cost of new delivery systems or missile bases" (Mitchell 1999, p. 55). President Johnson, notes Mitchell (1999), was politically able to propose reductions because of the significant increase in weapons procured during the short Kennedy administration. Ironically, deployment of MIRV under the following Nixon administration, together with a shift in national policy, led to an increase in the nuclear stockpile between 1971 and 1974.

On January 10, 1974, James Schlesinger, Secretary of Defense under Richard M. Nixon, formally set aside assured destruction when he announced "that the old policy…was no longer adequate for deterrence." The United States needed "a set of selective options against different sets of targets," primarily military rather than civilian. Called "flexible targeting," this policy emphasized "controlled escalation" (Mitchell 1999, p. 60). Prior to this policy shift, the military had equipped Minuteman III and Poseidon missiles with MIRV warheads in 1970 and 1971, respectively. Following this announcement, the military again pushed for new weapons, in particular the B-1 bomber and the MX missile. Mitchell (1999, p. 61) points out that the Nixon administration buildup, while increasing the number of weapons in the short term, actually reshaped the nuclear stockpile in the years following 1974. "The number of weapons retired from the stockpile, mostly tactical weapons, far outpaced the number of new weapons entering the stockpile, mostly strategic weapons." He argues that "the reduction in fissile material production, initiated by President Johnson in the mid-1960s, was beginning to have an impact on the number of new weapons deployed."

On May 26, 1972, the United States and the Soviet Union signed SALT I.

Even as he built up the U.S. nuclear arsenal, however, President Nixon signaled a desire to reduce the economic effects caused by the arms race. In his first inaugural address, delivered in January 1969, President Nixon told the world, "After a period of confrontation, we are entering a period of negotiation. Let all nations know that during this administration our lines of communication are open…With those who are willing to join us, let us cooperate to reduce the burden of arms, to strengthen the structure of peace" (Nixon, quoted in Walker 1995, p. 216). President Nixon was speaking of détente. Walker (1995, pp. 216-219) suggests that the "public perception of détente as a method of easing tensions was…an almost deliberate fraud [since] détente was the continuation of the Cold War in other places, and by more subtle means." However, President Nixon used détente as an opportunity to pursue arms control, which had the duel objective of reducing the defense budget and easing the debt created by the Vietnam War. The Anti-Ballistic Missile (ABM) Treaty, which President Nixon signed in 1972, addressed his inaugural message and represented the first attempt at mutual restraint between the United States and the Soviet Union. This treaty, which limited the "development and deployment of missiles designed to nullify each other's deterrent by shooting them down in flight," was a stabilizing measure that Walker (1995, p. 204) characterizes as the "first formal recognition that each superpower had an interest in protecting the strategic arsenal of the other." In the Strategic Arms Limitation Talks (SALT) that followed, the United States and Soviet Union sought to codify the number of nuclear weapons each could possess.

More direct than his predecessors, President Jimmy Carter, addressing the nation and the world in his inaugural speech in January 1977, stated bluntly: "We will move this year a step forward toward our ultimate goal – the elimination of all nuclear weapons from this earth" (Carter, quoted in Mitchell 1999, p. 62). Unfortunately for President Carter, the Soviet buildup initiated years before by Leonid Brezhnev "bore fruit with the introduction of four new models of strategic missiles in 1974…[and] the deployment of the SS-20 missiles [in Eastern Europe] in 1977" (Walker 1995, p. 244). While President Carter acted on his "moral conviction to rid the world of nuclear weapons" in signing SALT II on June 18, 1979 (Mitchell 1999, p. 62), the Soviets appeared to be gaining superiority (see sidebar box).

"U.S. interests appeared to be coming under threat throughout the world, with Soviet arms sales to Iraq and Syria, Soviet support for the PLO [Palestine Liberation Organization], the advance of the Soviet Union's Vietnamese allies throughout South-East Asia, and the new challenges to the pro-American regimes in Central America. The Kremlin's Cuban allies had established military control in Angola. On the maps of the world which American news magazines began to publish, with countries coloured in red for Soviet influence, the West's retreat was made to look graphically clear." **- Walker 1995, p. 246**

On December 27, 1979 Soviet Troops invaded Afghanistan and assassinated resistance leader Hafizullah Amin.

Dissatisfied from the start with his administration, the Committee on Present Danger, a conservative group of cold warriors, portrayed President Carter as ineffective and blamed him for turning the United States into a "weak and fading super-power" (Mitchell 1999, p. 64). On December 4, 1979, on the advice of National Security Advisor Zbigniew Brezinski, President Carter approved deployment of 200 MX missiles, a MIRV missile containing ten independently-targeted nuclear warheads. "The MX decision, and Carter's approval of the new Trident II SLBM [submarine launched ballistic missile], Pershing II IRBM [intermediate-range ballistic missile], and cruise missile…were measures by an administration perceived as weak, to demonstrate U.S. resolve, not only to the Soviets, but also to the American people" (Mitchell 1999, p. 63). In a classic case of bad timing, followers of the Ayatollah Khomeini seized the U.S. Embassy in Tehran on November 4, 1979 and held the diplomats and staff hostage for over a year thereby negating President Carter's decision in the eyes of the American public and much of the world. When the rescue attempt failed on April 24, 1980, the people handed the presidency to Ronald Reagan, who, like President Kennedy, had campaigned hard on a platform to restore "strong and decisive leadership and a strengthened nation" (Mitchell 1999, p. 65).

On September 22, 1980, Lech Walesa organized the Solidarity union in Poland.

Ronald Reagan "inherited a clear mandate for change, backed by a new American nationalism, and did not back away from the task at hand" (Mitchell 1999, p. 67). He increased spending on defense by 50 percent in his first 5 years in office. Twenty percent of that increase went to nuclear weapons, the remainder to conventional weapons.

Ironically, the "dramatic rearmament of the Reagan years was largely envisioned by the Carter Administration" (Walker 1995, p. 250). However, President Reagan seized the initiative. "Reagan's rearmament was an investment in national security. It was also the test of Reagan's private conviction that the United States could afford an arms race, while the Soviet Union could not. The Soviet Union would either have to renounce the arms race, or bankrupt itself into collapse in the vain effort to keep up" (Walker 1995, p. 267).

To compound the buildup, President Reagan proposed a new Strategic Defense Initiative (SDI), better known as "Star Wars," on March 23, 1983. President Reagan's call for a massive research project to develop a land- and space-based anti-missile system alarmed the Soviets, whose newly empowered Secretary General Yuri Andropov had proposed a series of initiatives for arms reductions, including "a 25 per cent cut in the strategic arsenals of both the USA and the Soviet Union, combined with a nuclear freeze on any new deployments" (Walker 1995, p. 272). It frightened the

Western Europeans, who believed they would become the target of choice for Soviet missiles if the United States were hidden behind a defensive shield and appeared to most observers to violate the mandates of the ABM Treaty of 1972. The SDI was a double-edged sword. It is credited by many as the final straw that broke the back of the Soviet economic resolve to continue the arms race. As Mitchell (1999, p. 67) points out: "Within four years the U.S. was spending approximately $6 billion annually on research and development for a Star Wars system. SDI would prove to be an up in the economic ante of the arms race that Gorbachev was unwilling or unable to match." It also delayed agreements on arms reductions by several years because of President Reagan's reluctance to give up the system. The Soviet Union, believing that the Reagan buildup and SDI were a repudiation of the Andropov "peace offensive" offered in 1982, became "convinced by its own propaganda that Reagan's America was capable of a pre-emptive nuclear attack" (Walker 1995, p. 277). Strategic Arms Reduction Talks (START), initiated in Geneva on June 29, 1982, made little progress by 1983. The Soviet Union then suspended the talks in December 1984.

Mikhail Gorbachev, a member of the new generation that Andropov believed "could help haul the country from Brezhnev's stagnant legacy," became Secretary General in March 1985 (Walker 1995, p. 272). Gorbachev's domestic agenda had three defining characteristics: "Sweeping economic reform with the profit motive, moves towards political democratization, and a much greater freedom for the Soviet press and media" (Walker 1995, p. 284). The essence of his reform movement was captured in two words, *perestroika* (restructuring) and *glasnost* (openness). The Solidarity movement in Poland, human rights activists in Czechoslovakia, and the democratic movements within Russia itself, fueled by the ever widening "peace movement" with its call for "No Nukes," emerged from the darkness into the light under Gorbachev. "Gorbachev's "Novoye Myshlenniye" or New Thinking in international affairs was first spelt out at the Geneva summit with President Reagan in October 1985, when they agreed in principle to work towards a Strategic Arms Reduction Treaty [START] to cut their nuclear arsenals in half. It was amplified in January of 1986, with Gorbachev's detailed scenario for nuclear disarmament by the year 2000" (Walker 1995, p. 290).

Meeting again in Reykjavik in October 1986, President Reagan and Secretary General Gorbachev acted on the exchange of ideas they had had on disarmament since their meeting in Geneva. They "agreed in principle" to eliminate medium-range nuclear missiles from Europe, eliminate all ABMs within 10 years, and eliminate tactical nuclear weapons. However, the "proposal to abolish nuclear weapons tumbled at the last fence, at Gorbachev's insistence that Reagan abandon his cherished SDI, or at least confine the research to the laboratory" (Walker 1995, p. 295). What President Reagan could not do, Congress did. With SDI scaled back, President Reagan and Secretary General Gorbachev signed the Intermediate Nuclear Forces (INF) Treaty in December 1987.

On June 3-4, 1989, Chinese forces violently ended the students' democratic movement in Tienanmen Square.

In December 1988, Gorbachev addressed the United Nations and set in motion the breakup of the Soviet Union. "Force or the threat of force," he said, "neither can nor should be instruments of foreign policy…Freedom of choice is a universal principle. It knows no exceptions" (Gorbachev, quoted in Walker 1995, p. 309). Taking him at his word, the people of Eastern Europe began to reclaim their countries, first Hungary, then Lithuania, Estonia, Latvia, and Poland, all within the first 6 months of 1989. East Germany left the Soviet fold in October 1989, destroying the Berlin Wall on November 10 to remove all doubt. Czechoslovakia followed on November 30 (Walker 1995, pp. 309-313). President George H. Bush and Secretary General Mikhail Gorbachev signed START in July 1991. Following a failed coup by communist hard-liners in Moscow in August, eight of the fifteen Soviet Republics declared complete independence. In an address to the nation on September 27, 1991, President Bush announced that he would destroy the nuclear artillery shells and warheads that had armed the tactical weapons based in Europe; withdraw all the tactical nuclear weapons from surface ships, submarines, and land-based naval aircraft; order the stand down of all strategic bombers and all the ICBMs scheduled for deactivation; and cancel those strategic weapons systems then in development (Mitchell 1999). With these actions, the United States and the Soviet Union ended the Cold War.

ECONOMIC DIVERSIFICATION: KEY TO SURVIVAL FOR THE HANFORD SITE

Site Name:	Hanford Works Hanford Reservation - January 1975 to September 1977 Hanford Site - October 1977 to 1990
Site Manager:	Donald G. Williams - June 1965 to November 1971 Thomas A. Nemzek - November 1971 to September 1973
Responsible Agency:	Atomic Energy Commission Energy Research and Development Administration - January 1975 to September 1977 Department of Energy - October 1977 to 1990
Site Contractor:	Douglas United Nuclear - November 1965 to August 1967 Reactor Operations, Fuel Manufacture
	United Nuclear Industries - September 1967 to April 1973 Reactor Operations, Fuel Manufacture UNC Nuclear Industries, Inc. - April 1973 to June 1987 Reactor Operations, Fuel Manufacture
	Isochem, Inc. - January 1966 to September 1967 Chemical Processing, Waste Management
	Atlantic Richfield Hanford Company - September 1967 to June 1977 Chemical Processing, Waste Management, Management and Integration
	Rockwell Hanford Operations - July 1977 to June 1987 Chemical Processing, Waste Management, Management and Integration
	Westinghouse - July 1970 to June 1987 Hanford Engineering and Development Laboratory, Fast Flux Test Facility
	Battelle - January 1965 to 1990 Pacific Northwest National Laboratory
	ITT Federal Support Services, Inc. - March 1966 to August 1971 Site Administrative Services and Infrastructure

Findlay and Hevly (1995, pp. 72, 78) repeatedly make the point that the Hanford Site was, above all else, a production center whose overriding mission was the "manufacture of as much fissionable material for bombs, as quickly and cost-efficiently as possible." Even as commercial applications began to expand, the Atomic Energy Commission "mandated that Hanford favor certain operations over research, and plutonium production over power production." However, this myopia began to change as defense production fell off rapidly after 1965.

In the mid-1960s, with three reactors already shut down, the Atomic Energy Commission, in concert with community leaders, looked for ways to maintain the viability of the industrial complex. If the Hanford Site were to survive, it clearly had to move beyond defense-related plutonium production. In a strong statement of the restructuring that would be necessary to achieve this objective, the Atomic Energy Commission and General Electric jointly announced the withdrawal of General Electric as the Hanford Site contractor on January 21, 1964. General Electric was not let go

because of poor management. Rather, the Atomic Energy Commission acted upon the prevailing perception that a single, large contractor countered effective regional economic development by removing the incentive for other businesses to come (Findlay and Hevly 1995). "In an effort to encourage the use of the site's resources and work force in new ways, the Commission increased its commitment to research activities and power production at Hanford, spread responsibility for managing Hanford's activities among several contractors, and required those contractors to invest in the local economy" (Findlay and Hevly 1995, pp. 217-218).

Finding ways to boost the local economy was imperative as the proportion of weapons-related federal support fell from nearly 100 percent in 1964 to only 25 percent in 1975.

POWER GENERATION

Congress did not approve the power plant that would produce and distribute electricity when it authorized construction of N Reactor in 1958. It voted down a proposal to use the built-in capability for conversion again in 1961. However, when the Washington Public Power Supply System (Supply System) agreed to pay all the expenses for the electrical generation and transmission facility, Congress passed the legislation necessary for a non-federal agency to construct and operate the facility on the Hanford Site on September 26, 1962.

Advocates for the facility, known as the Hanford Generating Plant, had waged a long political struggle against strong opposition from private utilities and the coal industry. Taking the long view, "business advocates saw dual-purpose reactors…as the point of entry for private enterprise into the nuclear arena" (Findlay and Hevly 1995, p. 170). Local advocates saw the Hanford Generating Plant as a way to "link Hanford's production mission to the long-delayed hopes for commercial nuclear power' (Findlay and Hevly 1995, p. 204).

President Kennedy had taken an interest in the Hanford Generating Plant, indeed his administration had placed the conditions on the authorizing legislation, particularly private funding, that won Congressional approval. Suitably, then, in a ceremony open to the public for the first time on the Hanford Site, Kennedy both dedicated N Reactor and initiated construction of the Hanford Generating Plant on September 26, 1963. Noting that it was "exactly one year ago today, after a long and bitter legislative battle, that I was able to sign the Hanford steam plant legislation," Kennedy went on to say that to "have permitted this resource to be wasted would have been in conflict with all the principles of resource conservation and utilization to which we are committed" (Kennedy, quoted in Stapp and Marceau 1996, pp. 18-19).

The Hanford Generating Plant first produced electricity on April 8, 1966. With the addition of the generating facility, N Reactor became the nation's first and only dual-purpose reactor. To produce electricity, operators pumped N Reactor primary cooling water to the 109-N Heat Exchange Building. Circulated through ten parallel heat exchangers, the heat from the process water caused water contained in a secondary system to boil and produce steam. This steam was transferred through overhead pipes to the 185-N Export Powerhouse Turbine Building where it drove two large turbines generating approximately 860 megawatts of electricity that was passed through the 155-N Export Power Switchyard to the Bonneville Power Administration power grid (UNI n.d., DOE 1997a).

In 1957, the Shippingport Reactor in Pennsylvania became the nation's first commercial nuclear-powered electrical generating facility. It was the first of many planned and constructed across the nation in the late 1950s and 1960s. Acting on the success of the Hanford Generating Plant, and in partial fulfillment of a bold local plan to establish a "nuclear power park" at the Hanford Site as a model for resolving the nation's "energy crisis" of the late 1970s, the Supply System proposed constructing three "electricity-generating reactors" – the first of up to twenty. Construction of the reactors began in 1980. However, the project was a huge financial drain and the Supply System terminated construction on two of the reactors in 1982. In 1983, Supply System "defaulted on its bonds, the largest default on municipal bonds in financial history." Only one of the Supply System reactors was completed and began producing electricity in 1984 "seven years later than initially planned" (Findlay and Hevly 1995, p. 296). In 1990, this reactor was the only active nuclear reactor at the Hanford Site.

SERVICE TO THE NUCLEAR AND SCIENTIFIC COMMUNITIES

As the Hanford Site production reactors shut down, fuel manufacturing and chemical separations activities decreased so that research and development programs now constituted the major mission. The research and development facilities included numerous laboratories and large test facilities in support of peaceful uses of plutonium, reactor fuels development, liquid metal technology, fast flux support, gas-cooled reactor programs, and life sciences programs.

Construction and operation of the Plutonium Recycle Critical Facility (PRCF) in 1963 indicated the efforts undertaken by the Atomic Energy Commission to promote local economic development and uncouple the Hanford Site from its historic reliance on national defense. Completed as a second addition to the 309 Building, General Electric designed PRCF to support PRTR operations. However, scientists soon began using PRCF to test experimental lattice systems in support of light-water-cooled reactor design. "A commercial license was obtained from the U.S. Nuclear Regulatory Commission along with special permits from the Atomic Energy Commission. These permits allowed the PRCF to operate as a private business venture, housing experiments for both government projects and for private nuclear fuel vendors until 1976" when the Energy Research and Development Agency (ERDA), Atomic Energy Commission's successor, closed the facility (Gerber 1993b, p. 35).

Originally a condition of their selection in 1965 as the Hanford Site contractor for chemical separations, Isochem, Inc. reneged on its promise to build a $9 million plant to recover and encapsulate radioisotopes from the Hanford Site high-level liquid waste stream. Commercial applications for the radioisotopes included food preservation, sterilization of medical supplies, and chemical manufacturing. However, unlike earlier successful isotope separations work conducted in the 325 High-Level Radiochemistry addition, Isochem determined no commercial market was available for the isotopes. Dissatisfied with Isochem's performance, the Atomic Energy Commission turned the chemical separations operation over to the Atlantic Richfield Hanford Company (ARHCO) in 1967 (Findlay and Hevly 1995). Initially, ARHCO did not pursue commercially based applications. Instead it modified the idle B Plant and provided its second mission, the recovery of cesium-137 and strontium-90 from high-level liquid waste. In 1974, ARHCO added the 225-B Waste Encapsulation and Storage Facility (WESF) to the B Plant complex. Here technicians solidified, encapsulated, and stored the recovered cesium and strontium. Operators completed cesium and strontium recovery in 1983 and 1985, respectively. These encapsulated isotopes were sent to the Oak Ridge National Laboratory for use in their isotope program.

In 1969, the Atomic Energy Commission decided to pursue breeder reactors instead of reactors fueled by mixed oxides. In an unanticipated decision, the Atomic Energy Commission selected the Hanford Site rather than the Argonne National Laboratory or the Idaho National Engineering and Environmental Laboratory as the location for the prototype Fast Fuel Test Reactor "even though production-oriented Hanford had no design team in place for such a new reactor" (Findlay and Hevly 1995, p. 243). Many of the facilities originally constructed for mixed oxide research were converted quickly for use in the Liquid Metal Fast Breeder Reactor program. For example, Westinghouse built a replica of a Fast Flux Test Facility (FFTF) operating cell within the 309 Building and used this facility to "train and requalify operators and to check operating procedures." The High Bay, added to the 308 Building in 1971, contained laboratories "for the initial storage, handling, testing, assembly, and instrumentation of FFTF fuel." In the late 1970s, specialists used the newly installed Training Research Isotopes, General Atomics (TRIGA) reactor to test FFTF fuel elements and jacket integrity (Gerber 1993b, p. 36). Metallurgists also conducted non-destructive examinations of FFTF fuel elements in the Shielded Materials Facility within the 324 Chemical Engineering Laboratory between 1968 and 1980.

To consolidate FFTF research and development, Westinghouse established the Hanford Engineering Development Laboratory. In addition to modifying existing facilities, Westinghouse constructed a number of new buildings within the 300 Area between 1968 and 1972 including the 335 Fast Reactor Thermal Engineering Facility, the 336 Core Segment Development Facility, and the 337 High-Temperature Sodium Facility. The 338 Building, originally constructed in the 100-F Area, was moved into the 300 Area in 1971 and served as the Components Mock-Up and Maintenance Facility to support FFTF. "In them, sodium loops tested various properties of sodium as a coolant, measured the behavior of

mechanical components in a sodium environment, and fabricated, assembled and decontaminated equipment" (Gerber 1992b, p. 41).

Construction of the FFTF (405 Building) began in 1970 and extended until 1978. Liquid sodium cooling allows neutrons to achieve higher energy levels than those possible or desirable in a water-cooled reactor. The flow of neutrons, or flux, is therefore faster. This characteristic of sodium-cooled reactors is reflected in the name of the facility. Engineers designed FFTF to operate at 400 megawatts-thermal. It went critical in February 1980. "FFTF was designed and constructed for the irradiation testing of fuels, core components and target assemblies for liquid metal fast breeder reactors. Reactor activities were later expanded to include long-term testing and evaluation of reactor components and systems, fusion power materials testing, passive [safety] testing and production [of] medical isotopes, and space power system research" (Gerber et al. 1997, p. 5.22).

As a final example of services the Hanford Site provided to the nuclear community, the Atomic Energy Commission designated the Plutonium Reclamation Facility (236-Z Building) as the Central Scrap Management Organization in 1972. The Plutonium Reclamation Facility would now recover and recycle plutonium from scrap materials shipped from defense and commercial facilities throughout the nation. "New defense grade oxides and metals could be made after Pu [plutonium] was reclaimed from these scraps, and commercial fuels…could be recycled and blended" (Gerber et al. 1997, p. 5-20).

In service to the biological, ecological, and medical communities, in 1970 Battelle constructed the Life Sciences Laboratory (331 Building) as a replacement for the 108-F Building. Between 1972 and 1984, Battelle added several ancillary support facilities including living areas for the test animals, an animal birthing facility, an animal waste treatment facility, a greenhouse, experimental areas, and warehouses. Continuing pioneering research on the effects of radiation on animals and plants, scientists in the 331 complex conducted studies "devoted to dosimetry, isotope preparation, plant physiology, terrestrial ecology, aquatic biology, and biochemistry." They also conducted research in "inhalation toxicology…virology, histology, hematology…histochemistry, pathology, and microbial physiology" (Gerber 1993b, p. 44). One accomplishment, among many, was the development of new techniques for heart surgery.

LAND RELEASES

The shutdown of reactors, Findlay and Hevly (1995, p. 244), assert "presented chances to diversify Hanford's economy in an environmentally sensitive way, an increasingly important consideration in light of the growing environmental movement." The Atomic Energy Commission had released lands before in response to economic pressures. In 1947, the Atomic Energy Commission, through its Advisory Committee on Reactor Safeguards, established a 280,000-acre safety zone around the three production reactors as a protective measure in the event of an accident within one or more of these facilities (see Figure 1.9). This safety zone, extending beyond the boundaries delineating the Hanford Site in 1943, was divided into a Control Zone and a Secondary Zone. The Control Zone, which the Atomic Energy Commission owned outright as part of the original land acquisition, consisted of the land nearest the reactors and adjacent to the Columbia River. While the Atomic Energy Commission did not own the Secondary Zone, which extended to the crest of the Saddle Mountains, they had successfully prevented any development on or use of these 192,000 acres. Herein lay the conflict.

The lands within the Secondary Zone had been slated for settlement and irrigation under the Columbia Basin Project initiated in 1933. In 1952, the Bureau of Reclamation pointedly told the Atomic Energy Commission that continued withdrawal of the Secondary Zone was "costly to the taxpayer and project and to the Pacific Northwest…[and a] loss to the nation" (Van Arsdol 1980, Attachment 1, p.2). Given mounting pressure from the local community, the Atomic Energy Commission announced on January 8, 1953 that it was releasing some 87,000 acres on the extreme east and west ends of the Secondary Zone. "We feel justified in making this determination on the basis of the knowledge and experience gained during eight years of safe and successful operation of the Hanford Works, during which the safety systems of the plant have steadily improved" (Atomic Energy Commission Commissioners quoted in Van Arsdol 1980, Attachment 2, p. 4).

This concession was insufficient since the Atomic Energy Commission also announced that while they would "permit the temporary construction of canals and roadways through the remaining restricted areas" they would continue to "oppose occupation or regular work there" (Findlay and Hevly 1995, p.122). With the hint of an impending lawsuit from the Columbia Basin Commission and following hearings held by Senator Jackson in October 1957, the Atomic Energy Commission released an additional 105,500 acres from the Secondary Zone on December 30, 1958, thereby reducing direct government control to the 560 square miles currently managed as the Hanford Site.

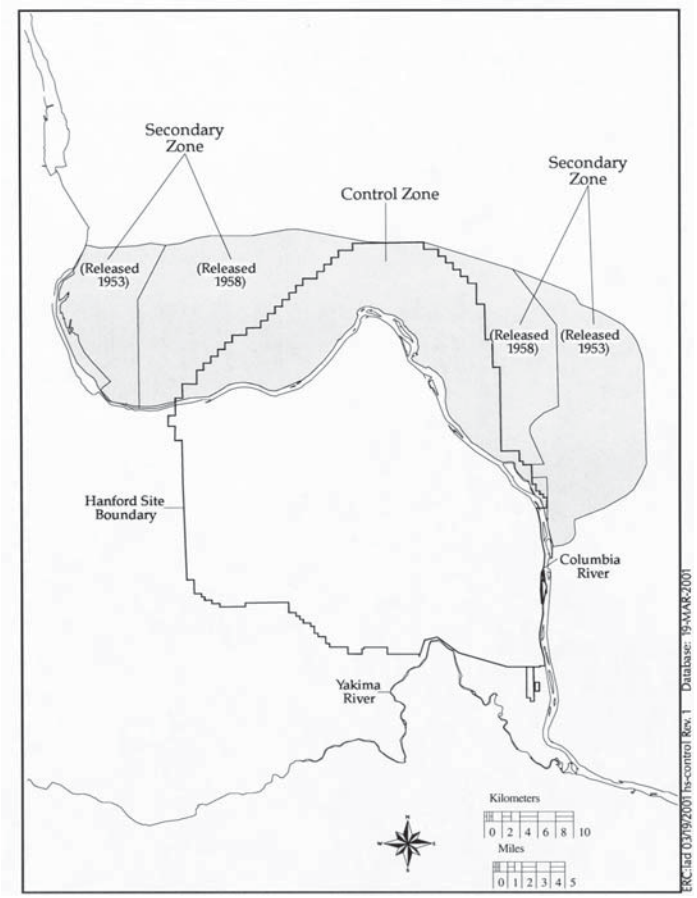


Figure 1.9. *Control Zone and Secondary Zones at the Hanford Site*

Pressure to release additional lands for economic development continued, but the Atomic Energy Commission found a new ally in the environmental movement. In response to two proposals centering on Rattlesnake Mountain and its adjacent slopes, the Atomic Energy Commission opted for biological and natural resource research rather than grazing and irrigation. On March 29, 1967, Senator Warren Magnuson announced the creation of the Arid Lands Ecology Reserve (now known as the Fitzner/Eberhardt Arid Lands Ecology Reserve) encompassing the southwestern edge of the Hanford Site. The Atomic Energy Commission set aside these 76,800 acres to "expand knowledge about man's relationship with nature, and thereby help protect the environment"(Findlay and Hevly 1995, p. 245). In discussing this decision further, Findlay and Hevly (1995, p. 247) assert that "proposals oriented more towards preservation gained precedence over economic development, largely because preservation dovetailed with a continuing emphasis on security at Hanford."

Continuing this trend, the Atomic Energy Commission established two additional natural resource areas. In 1971, the U.S. Fish and Wildlife Service assumed management of the Saddle Mountain National Wildlife Refuge on 32,000 acres of land within the western portion of the former Control Zone. That same year, the Washington State Department of Fish and Wildlife obtained management of 55,680 acres of the northern and eastern Control Zone designated as the Wahluke Wildlife Recreation Area. Figure 1.10 shows the additions since the Cold War Era of the Wahluke Wildlife Recreation Area, Saddle Mountain National Wildlife Refuge, Arid Lands Ecology Reserve, the 400 Area where the Fast Flux Test Facility is located, and the Washington Public Power Supply System.

REAGAN BUILDUP

Site Manager: Alex G. Fremling - September 1973 to June 1984
Responsible Agency: Department of Energy
Site Contractor: Westinghouse Hanford Company - June 1987 to 1990

The Atomic Energy Commission shut down D Reactor in June 1967. With four reactors now inactive, the Atomic Energy Commission closed REDOX in December 1967. Then, beginning with B Reactor in February 1968, the Atomic Energy

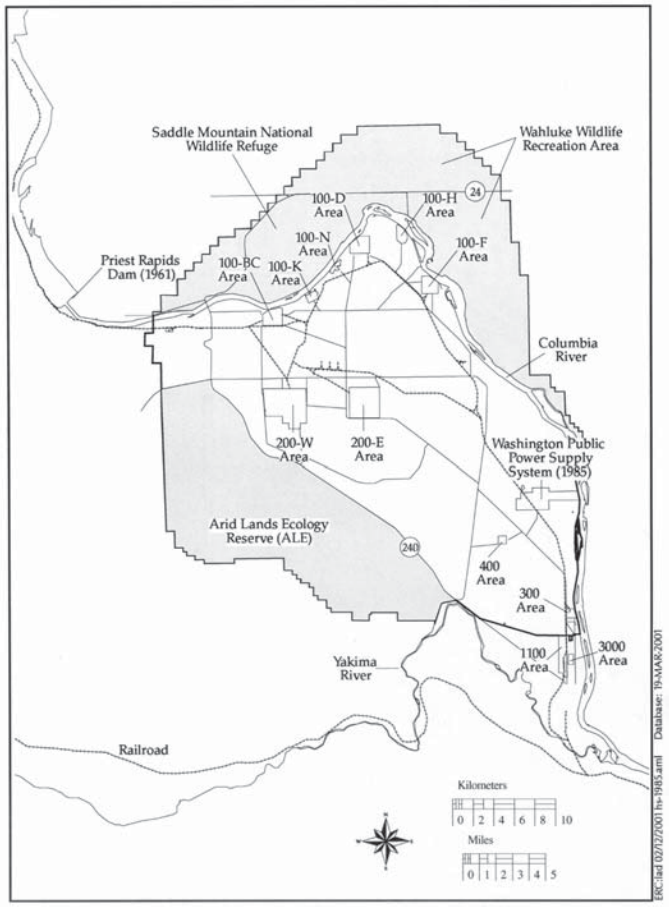


Figure 1.10. *Hanford Site Around 1985 Showing Additions Since the Cold War Era*

Commission ordered the closure of all remaining Hanford Site reactors in relatively quick succession: C Reactor in April 1969, KW Reactor in February 1970, and KE Reactor in January 1971. Only N Reactor expanded its operations to include steam production for the Hanford Generating Plant in 1966 and, for a short period between 1968 and 1970, tritium production. However, the Atomic Energy Commission order, issued for closure of the KE Reactor on January 26, 1971, also required the shutdown of the N Reactor.

Designed and operating now as a dual-purpose reactor, the prospect of loosing a facility that had barely begun fulfilling its commercial energy mission to the Pacific Northwest mobilized opposition against the Atomic Energy Commission decision to shutdown N Reactor. The Bonneville Power Administration, Supply System, Atomic Energy Commission, and the Federal Budget Office negotiated for 4 months, finally reaching an agreement in April 1971 that allowed N Reactor to remain in operation primarily to produce steam to turn the turbines for the Hanford Generating Plant. However, as a consequence of operations, N Reactor would also provide an additional service to the commercial reactor program. It would "pre-produce fuel-grade plutonium for the breeder reactor program" (Stapp and Marceau 1996, p. 24).

As the names indicate, weapons-grade plutonium was produced for weapon use, and fuel-grade plutonium was used as fuel for nuclear power reactors. In contrast to weapons-grade plutonium in which the level of the isotope plutonium-240 is kept below 7.4 percent, fuel-grade plutonium carries a plutonium-240 content of 7.4 percent or more. The N Reactor produced 8.2 metric tons of fuel-grade plutonium (12 percent plutonium-240) between 1973 and 1982. Unfortunately, this fuel-grade plutonium "was (and continues to be) stored in the fuel basins at the 100-K Reactors and was never used by the breeder reactor program as initially intentioned" (Stapp and Marceau 1996, p. 24). Because N Reactor would not be producing weapons-grade plutonium and PUREX was not equipped at the time to process commercial fuel, the Atomic Energy Commission placed PUREX on standby in June 1972.

To support the buildup of nuclear weapons initiated by President Carter and actuated by President Reagan, operators at N Reactor began producing weapons-grade plutonium in 1982. While DOE made the decision in 1980, it took nearly 2 years to upgrade the N Reactor before production could begin. "One fundamental problem was the distortion of the graphite stack, where built-in slip joints could not accommodate all of the local distortion, some block cleavage, and actual separation of blocks had occurred within the central core" (Gerber 1996, p. 2-10). Other issues involved system and facility maintenance on the aging structure as well as the implementation of new safety regulations issued by the U.S Nuclear Regulatory Commission. Westinghouse produced weapons-grade plutonium in N Reactor until 1987 when a number of unrelated events led to its closure.

By the mid-1980s, the international peace movement and its demand for disarmament made major inroads even within the Soviet Union. With the Intermediate Nuclear Forces Treaty nearly signed, and disagreements about strategic arms reduction narrowing, the need for additional plutonium had greatly diminished. Of more immediate concern was the

explosion and fire at the Chernobyl nuclear power plant on April 26, 1986. It raised concerns about the safety of N Reactor because of perceived design similarities. "After lengthy study of the plant's flaws and projected costs [for improvement], DOE decided in 1987 and [again in] 1988 not to restart it" (Findlay and Hevly 1995, p. 302). DOE ordered the reactor defueled in 1989. It never operated again.

In 1983, following an 11-year "temporary" shutdown, Westinghouse reactivated PUREX to process N Reactor weapons-grade fuel. During the period from 1972-1983, Westinghouse initiated numerous design changes, including a major conversion project that resulted in the production of plutonium oxide (metal) rather than plutonium nitrate (liquid) as the process end state. This allowed final processing to begin immediately upon receipt of the uranium metal at the Plutonium Finishing Plant. Other changes addressed "environmental concerns that led to providing upgraded filtration systems, seismic safeguards, backup power sources and many other projects" (Gerber 1996, p. 4-15). Additionally, under the Fuels Segregation Program from 1983-1984, PUREX operators also "extracted approximately 425 kilograms of weapon-grade plutonium…[from] some of the fuel assemblies discharged during the N-Reactor fuel grade campaigns" (DOE 1996b, Section 9.1.1). DOE placed PUREX on standby status in October 1990 after having effectively ended operations in December 1988.

Westinghouse operated the Plutonium Reclamation Facility and the RMC Line within the Plutonium Finishing Plant on an as-needed basis to support PUREX during the final defense run. The Plutonium Reclamation Facility reopened between 1984 and December 1987. The Plutonium Finishing Plant operated from 1985 to June 1989 (Gerber 1996, p. 5-5). Processed plutonium metal was stored within the Primary Plutonium Storage Facility (2736-Z Building). The design and configuration of the building's underground storage vaults, constructed between 1972 and 1973, remain classified.

To accept the high-level liquid wastes associated with chemical processing, various contractors built 28 new high-level liquid waste storage tanks between 1968 and 1986. Knowing that a number of the single-shell tanks had developed leaks, engineers developed a new design, the "tank-within-a-tank," referred to simply as a double-shell tank. Each tank had a capacity of 1 million gallons (Gerber et al. 1997, p. 5.83). It was also during this period that the Hanford Site contractors re-evaluated their waste management practices. Among the conclusions reached, they determined in 1970 that solid waste should be labeled and segregated by type before burial, that waste materials should be tracked, and that new burial grounds should be constructed in the 200 Area to receive all future solid wastes. In addressing high-level liquid wastes, contractors added two new Evaporators in 1974 (242-S) and 1976 (242-A) to augment the waste minimization program

TRANSITION TO CLEANUP

Site Manager:	Michael J. Lawrence (June 1984 to July 1990)
	John D. Wagoner (July 1990)
Responsible Agency:	U.S. Department of Energy
Site Contractor:	Westinghouse Hanford Company

Throughout the 1970s and 1980s, the environmental movement grew beyond any expectations held at its birth in the 1960s. "The nation's attitude toward energy in general changed, and its confidence in nuclear power in particular declined" (Findlay and Hevly 1995, p. 275). Popular films such as *The China Syndrome* moved public opinion with its depiction of the "meltdown" of a reactor core. Public reaction to this fictionalized account appeared subdued by contrast when, just a few weeks after the movie's release, the nation witnessed the real thing in 1979 in Pennsylvania at Three Mile Island. The explosion, fire, and subsequent global release of radionuclides from the Chernobyl accident in 1986 galvanized the anti-nuclear movement. "Around the state and around the nation, the growing doubts about nuclear energy and nuclear wastes found political support, and thereby affected Hanford's future. These changes in attitude came at a time when Hanford was particularly vulnerable in government" having lost their powerful Congressional delegates through death or political defeat (Findlay and Hevly 1995, p. 298).

> ***"The production of nuclear weapons had run continuously, beginning during World War II with the startup of the first reactor to produce plutonium for the top-secret Manhattan Project. But growing concerns about safety and environmental problems had caused various parts of the weapons-production complex to be shut down in the 1980s. These shutdowns, at first expected to be temporary, became permanent when the Soviet Union dissolved in 1991. The nuclear arms race of the Cold War came to a halt for the first time since the invention of the atomic bomb."*** **- DOE 1995e, p. 1**

Along with this lack of confidence in nuclear power, the public also began to change their attitude toward secrecy and security. While the need for secrecy and security arose from an external threat (the race with Germany to develop the atomic bomb and then the race with the Soviet Union to be the world power), the practices related to secrecy and security (classification of information, shredding of documents, surveillance of workers, etc.) also had the effect of preventing American citizens from gaining access to information about potential environmental degradation and health risks emanating from the Hanford Site.

The concept of a nuclear park died with the Supply System bond default. Defense production ended with the closures of N Reactor, PUREX, and the Plutonium Finishing Plant. Hanford Site administrators, with DOE's encouragement and assistance, sought one more time to find a national mission to store and manage the nation's nuclear waste. They saw their opportunity in the Nuclear Waste Policy Act of 1982. Under this legislation, Congress would select an eastern and a western repository among ten candidate sites. DOE spent $300 million examining the basalt formations of the Hanford Site, focusing primarily on Gable Mountain. This attention to the Hanford Site came at the expense of most of the alternative sites because of DOE's "perception that Washingtonians – or at least the state's elected officials – were more receptive to the idea of a repository than the people of other states" (Findlay and Hevly 1995, p. 298).

However in 1987, DOE cancelled all activity on the Basalt Waste Isolation Project on the Hanford Site and turned to Yucca Mountain in Nevada. "…the existence of an immense amount of waste at Hanford, and the record of its management and mismanagement over the years, provoked increasing public criticism. The waste itself, in other words, became a national crisis, so that Hanford was cast in the public mind as a problem rather than a solution to a problem" (Findlay and Hevly 1995, p. 274).

Cleaning up the Hanford Site became the mission. In May 1989, DOE, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology signed the *Hanford Federal Facility Agreement and Consent Order*, better known as the Tri-Party Agreement, which committed DOE to cleaning up the Hanford Site within 30 years. The signatories divided the Hanford Site into 78 Operable Units, each containing a number of "past practice" waste sites, each of which was to be investigated and remediated separately under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) program or the Resources Conservation and Recovery Act (RCRA) program.

With that, the Hanford Site's Manhattan Project and Cold War mission to produce weapons-grade plutonium finally ended. With each passing year, the once active industrial complex faded further into obscurity. Facilities for which there were no safety or security concerns, or those that were not needed to house personnel or materials for cleanup, or those with no future use were demolished or simply left unattended while they deteriorated. The 100 Area facilities were particularly hard-hit.

Beginning in 1972, Decontamination and Decommissioning (D&D) concentrated on the clean structures (those not contaminated with radioactivity) within the reactor complexes, such as those for water treatment. Demolitions increased or waned over the years, consistent with funding allocated to the task. During the late 1980s, D&D activity reached a peak as workers took down the majority of buildings within the reactor complexes, in many cases leaving little more than the reactor itself. As demolition and cleanup moved to the forefront, the history associated with a specific building became less important than the history of the wastes it produced. Given the health risk associated with much of that waste, it is critical that DOE understand where and how waste was generated and how to effect remediation.

On the other hand, under the Historic Preservation Program, it is also important that DOE shed light on the history of the facilities themselves, long-hidden behind national security and fences. At first glance, little distinguishes the mundane buildings distributed across the Hanford Site. Outwardly, they appear to comprise just another large industrial complex composed of production and support facilities. It is only after one looks behind the structural facades that their importance emerges.

The world-changing events associated with these buildings have local, state, national, and international significance that cannot be dismissed or denied. The Hanford Site mission both shaped and was shaped by world events in the last half of the 20th century. The buildings and structures remaining on the Hanford Site are the cumulative legacy and physical manifestation of that mission. This book introduces the reader to the science, technology, craftsmanship, and politics that infuse these facilities with meaning. The reader is encouraged to explore the events, processes, accomplishments, and failures that embody the story of the facilities and their role at the Hanford Site.

AREAS FOR FURTHER RESEARCH

The theme that the Hanford Site was an experiment runs throughout the Manhattan Project and the Cold War Era. Creating plutonium was a new science. Producing plutonium on an industrial scale was a major challenge. The time pressures of war and need for secrecy added to the uncertainties that accompanied each decision. Yet critical decisions had to be made within very short time frames despite the uncertainties. Because this book is a history of facilities and not intended to be the definitive history of producing plutonium at the Hanford Site, numerous facets of this theme of the Hanford Site as an experiment could not be explored. Hopefully future researchers will use this book as a springboard for their own studies to investigate such topics as the following:

- How was the geological history of the Hanford area affected by the load it had to bear when the Hanford Site was built?
- The yearly budgets for the Hanford Site have never been released to the public. When they are, future researchers would be able to evaluate the effect of the budgets over the years on the operations at the Hanford Site.
- How did the different corporate cultures of the various contractors, Du Pont and General Electric in particular, affect operations at the Hanford Site?
- Because the production of plutonium on an industrial scale was new and on a wartime schedule, workers had to be extraordinarily creative in making processes with which no one had experience work. A study of their creativity and the results would contribute greatly to understanding how the Hanford Site was able to produce plutonium against numerous odds.
- Developing an electronic, annotated bibliography of all references pertaining to the Hanford Site would facilitate future researchers' ability to find the particular information they seek.

OVERVIEW OF THE MANAGERS AND CONTRACTORS AT THE HANFORD SITE

Date	Contractor	Responsibility
Responsible Agency: U.S. Army Corps of Engineers		
Site Manager: Col.Franklin T. Matthias, 1943-1945 – Lt.Col.Fredrick J. Clarke, 1945-1947		
Site Name: Hanford Engineer Works		
1943-1946	**E. I. Du Pont de Nemours and Company**	**Prime Contractor** responsible for all activities
Responsible Agency: Atomic Energy Commission		
Site Manager: Carlton Shugg, 1947-1948 - Fred C. Schlemmer, 1948-1950 - David F. Shaw, 1950-1954 James E. Travis, 1955-1965 - Donald G. Williams, 1965-1971 – Thomas A. Nemzek, 1971-1973 - Alex G. Fremling, 1973 - 1984		
Site Name: Hanford Works		
1947–1974	**General Electric Company**	**Prime Contractor** responsible for all activities except as indicated
	Giffels & Vallet, Inc.	Engineering
	Charles T. Main	Engineering
	J. A. Jones	Construction Work
	Vitro Engineering, Co.	Architect-Engineer Services
	Douglas-United Nuclear, Inc.	Reactor Operations
	Isochem	Chemical Processing Operations
	Atlantic Richfield Hanford	**Prime Contractor** responsible for all activities except as indicated
	ITT Federal Support Services, Inc.	Support Services
	U.S. Testing Company	Bioassays, film badges, environmental samples
	Battelle Memorial Institute	National Laboratory
	Westinghouse Hanford Company	Fast Flux Test Facility
	Hanford Environmental Health Foundation	Health Services
Responsible Agency: Energy Research and Development Administration		
Site Manager: Alex G. Fremling 1973-1984		
Site Name: Hanford Reservation		
1975-1977	(see contractor list above)	
Responsible Agency: U.S. Department of Energy		
Site Manager: Michael J. Lawrence, 1984-1990, John D. Wagoner, 1990		
Site Name: Hanford Site		
1977-1990	**Rockwell Hanford Operations**	**Prime Contractor** responsible for all activities except as indicated above
	Westinghouse Hanford Company	**Prime Contractor** responsible for all activities except as indicated below
	ICF Kaiser Hanford Company	Architecture and Engineering
	Hanford Environmental Health Foundation	Health Services
	Battelle Memorial Institute	National Laboratory